STANDARDS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

1921

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PREFACE TO 1921 EDITION

PURPOSE OF THE STANDARDS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

In framing these standards the chief purpose has been to define the terms and conditions which characterize the rating and behavior of electrical apparatus, with special reference to the conditions of acceptance tests.

It has not been the purpose of the standards to standardize the dimensions or details of construction of any apparatus, lest the progress of design should be hampered

NOTE

The Standards Committee takes this occasion to draw the attention of the membership to the value of suggestions based upon experience gained in the application of the Standards to general practise.

Any suggestions looking toward improvement in the Standards should be communicated to the Secretary of the Institute for the guidance of the Standards Committee in the preparation of future editions.

DEVELOPMENT OF THE STANDARDS
OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

The A. I. E. E. recognized at an early date in the development of electrical engineering the importance of standardization of electrical apparatus and at a meeting of its members in January, 1898, there was an important discussion on the "The Standardization of Generators, Motors, and Transformers." This resulted in the appointment of a Committee on Standardization, consisting of seven members representing qualifications and experience from designing, manufacturing, and operating standpoints. The report of this Committee on standardization was presented and accepted at a meeting of the Institute in June, 1899, and the rules embodied became the authoritative basis of American practice.

Experience gained in applications of the Standardization rules and further developments in electrical apparatus and methods showed the necessity of revision, and a committee was appointed which after consultation with manufacturing and operating engineers presented the first revised report on Standardization Rules of the A. I. E. E. in June, 1902.

The next revision was undertaken by a committee of ten, which presented its report in May, 1906.

In September, 1906, a Standards Committee of eleven members was appointed for further revision, and its report was presented in June, 1907.

The appreciation of the importance and value of standardization resulted in the formation of a Standing Committee, with the title of Standards Committee of the A. I. E. E. This became effective in the Constitution of June, 1907. The scope and amount of work has necessitated increasing the number of members from time to time to the present membership of 37, within which are a number of sub-committees specializing on various subjects.

The Standards Committee is appointed each year by the President of the Institute and the practise has been to reappoint a number of the previous committee, so that it is practically a continuous operating body.

The present Standards of the A. I. E. E. are therefore the result of over twenty-one years of work on standardization by the Institute, conducted by members actively engaged in the design, manufacture, operation, and specifying of electrical apparatus. These men have freely contributed their time and knowledge, and have conducted much experimental work for the purpose. The Standards record the best American practise and experience.

SCOPE OF THE 1921 REVISION

This edition of the Standards has been completely revised in form. This was considered necessary in view both of certain intrinsic defects in the original form, and the increase in complexity due to this form not being adapted to receive the additions which are made from year to year. Furthermore several changes in substance have been made and a few sections added.

OTHER APPROVED STANDARDS

The following resolution, adopted by the Standards Committee, was approved by the Board of Directors on April 14, 1916:

"The Standards Committee, with the approval of the Board of Directors, recommends the use of the following rules and standards as adopted by other societies. These have been formally presented to the Standards Committee by the societies concerned and are found not to be incompatible with the Standards of the American Institute of Electrical Engineers."

Standardization of Service Requirements for Motors, as printed in the 1915 report of the National Electric Light Association.

Standardization of Sizes, Voltages and Taps for Transformers, as printed in the 1916 report of the Electrical Apparatus Committee of the National Electrical Light Association.

Standard Specifications for Magnetic Tests of Iron and Steel, of the American Society for Testing Materials.

Report of the Joint Rubber Insulation Committee, published in the April, 1917, PROCEEDINGS of the American Institute of Electrical Engineers.

Accuracy Specifications in Sections IV and V of the **Joint Meter Code** of the Association of Edison Illuminating Companies and of the National Electric Light Association.

Accuracy Specifications in Section II of Circular 56 of the Bureau of Standards entitled **Standards for Electric Service.**

Report of the **Boiler Code Committee** of the American Society of Mechanical Engineers.

Suggested Safety Rules for Installing and Using Electrical Equipment in Bituminous Coal Mines, issued as Technical Paper 138 by the Bureau of Mines.

COOPERATING SOCIETIES

The following societies directly and through the committees named, have given helpful cooperation in the preparation of these Rules:

American Society for Testing Materials,
Committee B-1.

Association of Edison Illuminating Companies,
Committee on Meters.

Illuminating Engineering Society,
Committee on Nomenclature and Standards.

Electric Power Club.
Committee on Engineering Recommendations; Standardization Committee.

National Electric Light Association
Committee on Meters.
Committee on Apparatus.

Association of Railway Electrical Engineers
Committee on Wires and Cables.

American Electric Railway Engineering Association,
Committees on Equipment and Distribution.

Institute of Radio Engineers,
Committee on Standardization.

Society of Automotive Engineers,
Standards Committee.

Railway Signal Association.

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STANDARDS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

CHAPTER I

GENERAL PRINCIPLES UPON WHICH THE A. I. E. E. STANDARDS ARE BASED

(All temperatures in this and the following chapters are given in centigrade degrees.)

HEATING

1000 **General Principles.**—The General Principles by reference to which the ratings of electrical machines are fixed, so far as their heating is concerned, admit that the life of insulating materials depends upon the temperatures to which these materials are subjected. Taking, as a basis, the results of experience with machinery in practical service and the results of laboratory tests of various insulating materials, limiting "hottest-spot" temperatures have been established for various classes of insulation *for purposes of standardization*. Limiting "observable" temperatures are deduced from these limiting "hottest-spot" temperatures by subtracting therefrom a specified number of degrees which, *for purposes of standardization* represents the margin fixed between the limiting hottest spot and the limiting observable temperatures.

This margin may be designated as the "*conventional allowance.*"

1001 **Methods of Temperature Measurement.**—There are three fundamental methods of temperature measurement, namely:

1. The Thermometer Method.
2. The Resistance Method, and,
3. The Embedded-Detector Method.

The General Principles stated in Section 1000 permit of the use of whichever method is best suited to the class of machine, or part thereof, to be tested, by introducing appropriate values for the limiting observable temperature by each method. All the values of the observable temperatures are based upon the "hottest-spot" limitation adopted *for purposes of standardization* for the class of insulation employed.

1002 **Methods of Temperature Measurement Defined.**—These three fundamental methods of making temperature measurements are designated Methods 1, 2 and 3, and are defined as follows:

TABLE 100

Methods of Temperature Measurement

Method	Description of Method
1.	**Thermometer Method.** This method consists in the measurement of the temperature, by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest accessible part of the completed machine. This method does not include the use of thermocouples or resistance coils embedded in the machine as described under Method No. 3.
2.	**Resistance Method.** This method consists in the measurement of the temperature of windings by their increase in resistance. In the application of this method, *thermometer measurements shall also be made whenever practicable without disassembling the machine,** in order to increase the probability of obtaining the highest observable temperature. The measurement indicating the higher temperature shall be taken as the "observable" temperature.
3.	**Embedded Temperature-Detector Method.** This method consists in the measurement of the temperature by thermocouple or resistance temperature detectors, located as nearly as possible at the estimated hottest spot. When Method No. 3 is used, it shall, when required be checked by Method No. 2. The highest observable temperature obtained from the readings of the embedded detectors shall not exceed the values permitted by the Rules for Method 3, and the highest observable temperature obtained by Method 2 shall not exceed the values permitted by the Rules for Method 2.

*Note. As one of the few instances in which the thermometer check cannot be applied in Method II, the rotor of a turbo alternator may be cited.

1003 Conventional Allowances for the Three Methods of Temperature Measurement.—The specified differences by which the "observable" temperatures shall, *for purposes of standardization*, be assumed to be lower than the "hottest spot" temperatures, (which may be designated the "Conventional Allowances"), are as follows:

Method 1.....................15°C
" 2.....................10°C
" 3.....................(See following table).

TABLE 101

Conventional Allowance for Method 3

Method 3.	
For windings with two coil-sides per slot with detectors between top and bottom coil-sides (and between coil-sides and core).	5°C
For windings with one coil-side per slot for 5000 volts or less, with detectors between coil-side and core and between coil-side and wedge.	10°C
For windings with one coil-side per slot for more than 5000 volts, with detectors between coil-side and core and between coil-side and wedge.	10°C plus 1°C for every kv. of terminal pressure of the machine above 5 kv.

1004 Classification of Insulating Materials.—The insulations employed in Electrical Machinery are subdivided into three main classes, designated A, B and C and defined as follows:

TABLE 102

Classification of Insulating Materials

Class	Description of Material.
A.	Cotton, silk, paper and similar materials when so treated or impregnated as to increase the thermal limit, or when permanently immersed in oil; also enamelled wire. When these materials are not treated, impregnated, or immersed in oil, they are not included in Class A.
B.	Mica, asbestos and other materials capable of resisting high temperatures, in which any Class A material or binder is used for structural purposes only, and may be destroyed without impairing the insulation or mechanical qualities of the insulation. (The word "impair" is used in the sense of causing any change which could disqualify the insulation for continuous service.)
C.	Materials capable of resisting higher temperatures than Class B, such as pure mica, porcelain, quartz, etc.

1005* **Limiting "Hottest Spot" Temperatures.**—The limiting "hottest spot" temperatures are, *for purposes of standardization*, taken at the following values:

For Class A material...........105°C (See Note 1)
For Class B material...........125°C (See Note 2)
For Class C material...........no limit yet specified.

If different insulating materials are used on various parts of one winding (for instance in the slot and for the end windings) the temperature of each material shall not exceed the limit set for that material.

When insulation consists of layers of materials having different temperature-limits (for instance high-temperature limit material adjacent to the copper and lower-temperature limit material adjacent to the iron or to the air) the temperature of each material shall not exceed the limit set for that material.

1006 **Limiting Observable Temperatures.**—The limiting observable temperatures for use with methods 1, 2 and 3, are arrived at by subtracting the "conventional allowances" from the limiting "hottest-spot" temperatures for insulating materials. They are set forth as follows:

TABLE 103
Limiting Observable Temperatures

		Class A Material	Class B* Material
Method 1		90° C.	110° C.
Method 2		95° C.	115° C.
Method 3	For windings with two coil-sides per slot with detectors between top and bottom coil-sides and between coil-sides and core.	100° C.	120° C.
	For windings with one coil-side per slot with detectors between coil-side and core and between coil-side and wedge.	95° C. (minus 1 degree for every 1000 volts of terminal pressure of the machine above 5000 volts).	115° C. (minus 1 degree for every 1000 volts of terminal pressure of the machine above 5000 volts).

*See also note 2 Section 1005.

(1005) Note 1. For cotton, silk, paper and similar materials when neither treated, impregnated nor immersed in oil, the limits of observable temperature and temperature rise shall be 15°C below the limits fixed for these materials when impregnated.

(1005) Note 2. The Institute recognizes the ability of manufacturers to employ Class B insulation successfully at maximum temperatures of 150°C or even higher. However, as sufficient data covering experience over a period of years at such temperatures are at present unavailable, the Institute adopts 125°C as a conservative limit for this class of insulation, and any increase above this figure should be the subject of special guarantee by the manufacturer.

1007 Limiting Observable Temperature of Oil.—The oil in which apparatus is permanently immersed, shall, in no part, have a temperature, observable by thermometer, in excess of 90°C.

1008 Standard Ambient Temperatures of Reference.—The following values are adopted for the standard ambient temperatures of reference:

For Air....................................40°C
For Water..................................25°C

These values for the standard ambient temperatures of reference apply to all conditions where the actual ambient temperature does not exceed them.

The limiting observable temperature rise must not be increased even when the ambient temperature is lower than the standard ambient temperature of reference.

1009 Limiting Observable Temperature Rises.—The limiting observable temperature rises in the following table 104 are obtained by subtracting the standard ambient temperatures of reference given in §1008 from the limiting observable temperatures given in Table 103. The limiting observable temperature rises to be used in practise are given later in the Rules. They are in some cases greater and in other cases smaller than those given in Table 104. See §1010

TABLE 104
Limiting Observable Temperature Rises

		Air Cooled	
		Class A	Class B*
Method 1		50°C	70°C
Method 2		55°C	75°C
Method 3	For windings with two coil-sides per slot, with detectors between top and bottom coil-sides and between coil-sides and core.	60°C	80°C
	For windings with one coil-side per slot with detectors between coil-side and core and between coil-side and wedge.	55°C (minus 1 degree for every 1000 volts of terminal pressure of the machine above 5000 volts).	75°C (minus 1 degree for every 1000 volts of terminal pressure of the machine above 5000 volts).

*See also Note 2, Section 1005

1010 **General Comments on Special and Specific Cases.**—In the foregoing it has been assumed for the purpose of presenting a comprehensive, logical and consistent plan, that the Rules actually used in the industry are exactly in accord with the General Principles. Practical experience indicates the necessity of establishing definite Rules to cover Special as well as Specific Cases. These Cases are set forth in later chapters. Any case not specifically dealt with may come under the General Principles.

1011 **Comments on the Method of Measurement to be Employed.**—In the absence of definite Rules, the manufacturer may, on the occasion of the acceptance test, use any of the three methods for the temperature measurements. In most cases, however, restrictions on the choice of method are imposed. These are set forth in the Rules.

1012 **Comments on Temperature Limits in Special Cases.**—Temperature limits are prescribed in the Rules for special cases where conditions determined by practice, by experience, or by agreements, require departures (often arbitrary) from the limits of temperature rise corresponding to the General Principles.

1013 **Hottest Spot Temperature the Primary Point of Reference.**—The hottest spot temperature is the primary point of reference, of the "bench-mark" used as the basis for the foregoing scheme or temperature delimitation. It is not employed in commercial transactions or in the ordinary course of testing or operation of electrical machinery.

1014 **Observable Temperature Rise the Working Standard.**—The observable temperature rise is the working standard. A summary of working data with explanatory notes, will be found in Table 200.

1015 **Duration of Temperature Test and Correction to Time of Shut Down.**—Whatever method of temperature measurement be employed, it is required that

(a) operation shall be continued until constant temperatures are determined if the machine has a continuous rating, or for the full period if the machine has a short time rating, and

(b) when measurements cannot be made while the machine is loaded, appropriate corrections to raise the temperature readings to the time of shut down shall be applied. See Chap. II.

MECHANICAL AND COMMUTATION LIMITATIONS.

These limitations are set forth in subsequent Chapters dealing with specific kinds of machines.

WAVE SHAPE.

1200 The sine wave shall be considered as standard except where the departure therefrom is inherent in the operation of the system of which the machine forms a part.

DIELECTRIC STRENGTH AND INSULATION RESISTANCE.

(See §§2350 to 2380 incl.)

1300—The injury produced by dielectric stress applied to insulation is related to the time during which the stress is applied. A stress up to a certain limit may be applied for an indefinite period without injury to the insulation. A somewhat greater stress will cause heating of the insulation and a progressive deterioration, eventually resulting in breakdown. Higher values of stress cause more rapid deterioration and a quicker breakdown. It is customary to determine whether machinery will withstand the voltage stresses met in practice by a preliminary test for a definite period of time at a voltage considerably higher than the normal voltage to which the machinery is to be subjected, but not high enough to produce injury to the insulation during the period of test.

1301—The test voltage which shall be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the machine, and its operating voltage, upon the nature of the service in which it is to be used, and upon the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended have been determined as reasonable and proper for the great majority of cases, and are proposed for general adoption, except when specific reasons make a modification desirable.

1400—The insulation resistance of machinery is of doubtful significance as compared with the dielectric strength. It is subject to wide variation with temperature, humidity and cleanliness of the parts. When the insulation resistance falls below prescribed values it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying the machine. The insulation resistance therefore may afford a useful indication as to whether the machine is in suitable condition for application of the dielectric test.

EFFICIENCY

(See §§2331 to 2333 incl.)

1500 The conditions under which efficiency is determined are those normal to the operation of the machine. These include voltage, current, power factor, frequency, wave shape, speed, temperature, or such of them as may apply in each particular case.

1501 The efficiency at all loads of all apparatus shall be corrected to a reference temperature of 75°C.

1502 In the case of machinery, two efficiencies are recognized, conventional efficiency (§**3524**) and directly measured efficiency. Unless otherwise specified, the conventional efficiency is to be employed. When the efficiency of a machine is stated without specific reference to the load conditions rated load is always to be understood, whether the efficiency be the conventional or directly measured efficiency.

RATING

(See §§2202 to 2232 incl.)

1600 Principle of Machine Rating.—(a) *Rating by Temperature Rise*: The principle upon which machine rating is based, so far as relates to thermal characteristics, has been stated in earlier sections.

(b) *Rating by Limitations Other Than Temperature Rise*: In some machines, the rating is limited by other than thermal considerations. In such cases, the principle upon which machine rating is based is that the rated load applied continuously or for a stated period, shall not cause the various limitations specified in later chapters; *e. g.*, §§**4250-4252** inclusive, to be exceeded. The rating shall be based upon the capacity as limited by heating unless the capacity as limited by other characteristics, is less.

CHAPTER II.

GENERAL RULES

The expressions "machinery" and "machines" are here employed in a general sense, in order to obviate the constant repetition of the words "machinery or induction apparatus."

To ensure satisfactory results, electrical machinery should be specified to conform to the Institute Standards, in order that it shall comply in operation, with approved limitations in the following respects, so far as they are applicable.

Operating temperature
Mechanical strength
Commutation
Dielectric strength
Insulation resistance
Efficiency
Power factor
Wave shape
Regulation

OPERATION

Temperature Limits

2104 **Permissible Temperatures with Insulations of More Than One Class.**—(a) If different insulating materials are used on various parts of one winding (for instance in the slot and for the end windings) the temperature of each material shall not exceed the limit set for that material.

(b) When insulation consists of layers of materials having different temperature limits (for instance high-temperature-limit material adjacent to the copper and lower-temperature-limit material adjacent to the iron or to the air) the temperature of each material shall not exceed the limit set for that material.

2116 **Temperatures of Metallic Parts of Machines.**—(*a*) *Parts Adjacent to Insulating Material*: Metallic parts of machines in contact with or adjacent to any kind of insulation, shall not attain a temperature in excess of that allowed for the adjacent insulation.

(*b*) *Parts not Adjacent to Insulating Material*: All parts of machines other than those covered by §**2116** (a) may be operated at such temperatures as shall not be injurious in any other respect.

2120. Protection against Short Circuit.—The Institute recognizes the self-destructibility, both mechanical and thermal, of certain sizes and types of machines, when subjected to severe short-circuits, and recommends that ample protection be provided in such cases, external to the machine if necessary.

RATING

General

2202 **Expression of Rating.**—Except where otherwise specified the machines shall be rated in terms of their available *output*. For exceptions see §§**4223, 5203, 6204** and **6223.**

2204 **Institute Rating.**—The Institute Rating of a machine shall be its rating when operating with a cooling medium of the ambient temperature of reference specified in §§**2211** and **2212** and with barometric conditions within the range given in §**2215**. See §§**2300, 2310, 2311, 4110** and **4300.**

Ambient Temperature of Reference and Altitude Correction

2211 **Ambient Temperature of Reference for Air.**—The standard ambient temperature of reference, when the cooling medium is air, shall be 40°C.

2212 **Ambient Temperature of Reference for Water-Cooled Machinery.**—For water-cooled machinery, the standard temperature of reference for incoming cooling water shall be 25° C, measured at the intake of the machine.

2213 **Machines Cooled by Other Means.**—Machines cooled by means other than air or water shall receive special consideration.

2214 **Outdoor Machinery Exposed to Sun's Rays.**—Outdoor machinery not protected from the sun's rays at times of heavy load, shall receive special consideration.

2215 **Altitude.**—Increased altitude has the effect of increasing the temperature rise of some types of machinery. In the absence of information in regard to the height above sea level at which a machine is intended to work in ordinary service, this height is assumed not to exceed 1000 meters (3300 feet.) For machinery operating at an altitude of 1000 meters or less, a test at any altitude less than 1000 meters is satisfactory, and no correction shall be applied to the observed temperatures. Machines intended for operation at higher altitudes shall be regarded as special. It is recommended that when a machine is intended for service at altitudes above 1000 meters (3300 ft.) the permissible temperature rise at sea level, shall be reduced by 1 per cent for each 100 meters (330 ft.) by which the altitude exceeds 1000 meters.

Kinds of Rating

There are various kinds of rating such as:

2220 **Continuous Rating.**—A machine rated for continuous service shall be able to operate continuously at its rated output, without exceeding any of the limitations established herein.

In the absence of any specification as to the kind of rating, the continuous rating shall be understood.

2221 Short-Time Rating.—A machine rated for discontinuous or short-time service (*i. e.* service including runs alternating with stops of sufficient duration to ensure substantial cooling), shall be capable of operating at its rated output during a limited period, to be specified in each case, without exceeding any of the limitations established herein. Such a rating is a short-time rating.

2222 Duty-Cycle Operation.—Many machines are operated on a cycle of duty which repeats itself with more or less regularity. For purposes of rating, either a continuous or a short-time equivalent load may be selected, which shall simulate as nearly as possible the thermal conditions of the actual duty-cycle.

2223* Standard Short-Time Ratings.—The following periods shall be used for short-time ratings: 5, 10, 15, 30, 60 and 120 minutes.

2224 A.I.E.E. and I. E. C. Ratings.—When the prescribed conditions of test are those of the A. I. E. E. Standards the rating of the machine is the Institute Rating. (See §**2401**) When the prescribed conditions of the test are those of the I. E. C. Rules, the rating of the machine is the I. E. C. rating. A machine so rated in either case may bear a distinctive sign upon its rating plate. I. E. C. stands for "International Electrotechnical Commission."

2225 Continuous Rating Implied.—Machines marked "A. I. E. E. Rating" or "I. E. C. Rating" shall be understood to have a continuous rating, unless otherwise marked in accordance with §§**2223, 5201** or **5202**.

Rating by Temperature Rise

2230 Limiting Observable Temperature Rises.—The following limiting observable temperature rises have been adopted.

(2223) When, for example, a short-time rating of 10 minutes duration is adopted, and the thermally equivalent load is 25 kw. for that period, then such a machine shall be stated to have a 10-minute rating of 25 kw.

In every case the equivalent short-time test shall commence only when the windings and other parts of the machine are within 5° C. of the ambient temperature at the time of starting the test.

TABLE 200

Limiting Observable Temperature rises for machines for operation in locations where the ambient temperature will not exceed 40°C. for Air or 25°C. for Water.

For Class A insulation use the values in the Table
For Class B insulation use 20 °C. higher values (or 45°C. higher in the cases covered by the Note in §**1005**).
For Class C insulation no limits yet specified.

	Items	Method 1	Method 2	Method 3: For windings with two coil-sides per slot with detectors between top and bottom coil-sides and between coil sides and core.	Method 3: For windings with one coil-side per slot with detectors against core and against wedge.
Windings on Stators	1–Insulated windings other than 2.3. Note 1	50°C. Note 1	55°C. Note 1	60°C. Note 1	55°C. minus 1° for every 1000 volts by which the terminal pressure of the machine exceeds 5000 volts). Note 1
Windings on Stators	2–Single layer field windings with exposed surfaces uninsulated	60°C.	60°C.		
Windings on Stators	3–Short circuited insulated windings	60°C.			
Windings on Rotors	4–Field Windings (other than 5.)		55°C.		
Windings on Rotors	5–Single layer field windings with exposed surfaces uninsulated	60°C.	60°C.		
Windings on Rotors	6–Windings in slots	50°C.	55°C.		
Windings on Rotors	7–Short-circuited insulated windings	60°C.			
	8–Transformers and Induction Regulators		55°C.		

Note 1—(a) The temperature of the windings of transformers and induction regulators is always to be ascertained by Method 2.

(b) In measuring the temperature of air blast transformers, the air supply shall be shut off immediately at the end of the temperature run and air intake shall

be closed to prevent further admission of cooling air. In checking the temperatures ascertained by resistance, the readings of thermometers well distributed and in good contact with the coils shall be noted and the maximum temperature indicated by them, if higher than that determined by resistance, shall be taken as the maximum observable temperature of the windings. With the above procedure, the observable temperature rise for air-blast transformers may attain a value not in excess of 60°C. as determined by thermometer, although it must not exceed 55°C. as determined by resistance.

(c) Method 3 shall be applied to all stators of machines with cores having a width 50 cm. and over; it shall also be applied to all machines of 5000 volts and over if of over 500 kv-a. regardless of core width.

(d) Method 2 shall not be used for circuits of low resistance (other than transformer windings), such as interpole windings, where external joints and connections form a considerable part of the total resistance.

(e) For all other cases it is optional to employ either Method 1 or Method 2. (This is equivalent to authorizing Method 1 with a 5°C. lower limit of observable temperature than is permitted for Method 2).

Note 2.—For cotton, silk, paper and similar materials when neither treated, impregnated nor immersed in oil, the limits of observable temperature rise shall be 15 degrees below the limits in the above table fixed for these materials when impregnated.

Note 3.—For enclosed machines (rotating) the limiting observable temperature rise shall be taken as 5 degrees higher than the values set forth in the Table for Items 1 and 6.

Note 4. A further limitation to this Table relates to the restriction of its application to machinery for operation in locations whose altitude is not more than 1000 meters above sea level. Recommendations relating to the limiting temperature rise for machines for operation at higher altitudes are given in §§2215 and 2231.

Note 5. If different insulating materials are used on various parts of one winding (for instance in the slot and for the end windings) the temperature of each material shall not exceed the limit set for that material.

When insulation consists of layers of materials having different temperature limits (for instance high-temperature limit material adjacent to the copper and lower temperature limit material adjacent to the iron or the air) the temperature of each material shall not exceed the limit set for that material.

2231 **Exceptions to Table 200.**—(a) For cotton, silk, paper and similar materials when neither treated, impregnated nor immersed in oil, the limits of observable temperature rise shall be 15°C. below the limits fixed for these materials when impregnated.

(b) When the thermometers are applied directly to the surfaces of bare windings, such as an edgewise strip conductor, or a cast copper winding, the limiting observable temperature rise shall be 10°C. higher than given for Method 1 in the Table.

(c) For commutators, collector rings, or bare metallic surfaces not forming part of a winding, the limiting observable temperature rise shall be 15°C. higher than given for Method 1 in the Table.

(d) Any machinery destined for use with higher ambient temperatures of cooling mediums, and also any machinery for operation at altitudes for which no provision is made in §2215, should be the subject of special guarantee by the manufacturer. The methods of test and performance set forth in these Rules, will, however, afford guidance in such cases.

2232 **Limiting Observable Temperature of Oil.**—The oil in which apparatus is permanently immersed shall, in no part, have a temperature, observable by thermometer, in excess of 90°C.

TESTS

Ambient Temperature

2300* Measurement of the Ambient Temperature During Tests of Machinery.—(*a*) *General:* The ambient temperature is to be measured by means of several thermometers placed at different points around and half way up the machine at a distance of 1 to 2 meters (3 to 6 feet), and protected from drafts, and abnormal heat radiation, preferably as in §**2301**.

(*b*) *Mean Temperature*: The value to be adopted for the ambient temperature during a test, is the mean of the readings of the thermometers (placed as above), taken at equal intervals of time during the last quarter of the duration of the test.

(*c*) *Use of Idle Unit*: It is sometimes desirable to avoid errors due to time lag in temperature changes, by employing an idle unit of the same size and subjected to the same conditions of cooling as the unit under test, for obtaining the ambient temperature.

2301 Oil Cup.—In order to avoid errors due to the time lag between the temperature of large machines and the variations in the ambient air, all reasonable precautions must be taken to reduce these variations and the errors arising therefrom. Thus, the thermometer for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, in a suitably heavy metal cup. This can be made to respond to various rates of change, by proportioning the amount of oil to the metal in the containing cup. A convenient form for such an oil cup consists of a massive metal cylinder, with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed therein with its bulb well immersed. The larger the machine under test, the larger should be the metal cylinder employed as an oil cup in the determination of the ambient temperature. The smallest size of oil cup employed in any case shall consist of a metal cylinder 25 mm. in diameter and 50 mm. high (1 in. in diameter and 2 in. high).

Machine Temperatures

2310 Temperature Rise for Any Ambient Temperature.—A machine may be tested at any convenient ambient temperature, preferably not below 10°C., but whatever be the value of this ambient temperature, the permissible rises of temperature must not exceed those given in Table 200.

2311 Correction for the Deviation of the Ambient Temperature of the Cooling Medium, at the Time of the Heat Test, from the Standard Ambient Temperature of Reference.—Numerous experiments have shown that deviation of the temperature of the cooling medium from that of the standard of reference, at the time of the heat run, has a negligible effect upon the temperture rise of machines; therefore, no correction shall be applied for this deviation.

(2300) The cooling fluid may either be led to the machine through ducts, or through pipes, or merely surround the machine freely. In the former case the ambient temperature is to be measured at the intake of the machine itself.

2312 Duration of Temperature Test of Machine for Continuous Service.—The temperature test shall be continued until sufficient evidence is available to show that the maximum temperature and temperature rise would not exceed the requirements of the rules, should the test be prolonged until the attainment of a steady final temperature.

2313 Duration of Temperature Test of Machine with a Short-Time Rating.—The duration of the temperature test of a machine with a short-time rating shall be the time required by the rating. In every case the equivalent short-time test shall commence only when the windings and other parts of the machine are within 5°C. of the ambient temperature at the time of starting the test. See §**2235.**

2314 Duration of Temperature Test for Machine having more than One Rating.—The duration of the temperature test for a machine with more than one rating shall be the time required by that rating which produces the greatest temperature rise. In cases where this cannot be determined beforehand, the machine shall be tested separately under each rating.

2315 Temperature Measurements during Heat Run.—When possible temperature measurements shall be taken during operation, as well as when the machine is stopped. The highest figures thus obtained shall be adopted. In order to abridge the long heating period, in the case of large machines, reasonable overloads of current during the preliminary period are suggested for them.

2316 Rules for Correcting to Time of Shut-Down.—(a) Whenever a sufficient time has elapsed between the instant of shut-down and the time of the final temperature measurement to permit the temperature to fall, suitable corrections shall be applied, so as to obtain as nearly as practicable the temperature at the instant of shut-down. This can sometimes be approximately effected by plotting a curve with temperature readings as ordinates and time as abscissas, and extrapolating back to the instant of shut-down. In other instances, acceptable correction factors can be applied; *e. g.*, In the case of machines manufactured in large quantities, the correction obtained from tests made on representative machines may be used.

(b) Exception. In cases where successive measurements show *increasing* temperatures after shut-down, the highest value shall be taken.

Details of Testing Methods

2320 Covering of Thermometer.—Thermometers used for taking temperatures of machinery shall be covered by felt pads 4 cm. x 5 cm. (1½ in. x 2 in.), 3 mm. (⅛ inch) thick cemented on; oil putty may be used for stationary and small apparatus.

2321 Temperature Coefficient of Copper.—The temperature coefficient of copper shall be deduced from the formula $1/(234.5 + t)$. Thus, at an initial temperature $t = 40°C.$, the temperature coefficient of increase in resistance per degree centigrade rise is $1/(274.5 = 0.00364)$. The following table, deduced from the formula, is given for convenience of reference.

TABLE 201

Temperature Coefficients of Copper Resistance.

Temperature of the winding, in degrees C. at which the initial resistance is measured.	Increase in resistance of copper per °C., per ohm of initial resistance.
0	0.00427
5	0.00418
10	0.00409
15	0.00401
20	0.00393
25	0.00385
30	0.00378
35	0.00371
40	0.00364

2322 Temperature Measurement of Low Resistance Circuit.—In circuits of low resistance, where joints and connections form a considerable part of the total resistance, the measurement of temperature by the resistance method shall not be used. (Except transformers, for which see §**6320**.)

2323* Location of Embedded Temperature Detectors.—Embedded temperature detectors should be placed in at least two sets of locations. One of these should be between a coil-side and the core and one between the top and bottom coil-sides where two coil-sides per slot are used. Where only one coil-side per slot is used, one set of detectors shall be placed between coil-side and core, and one set between coil-side and wedge. A liberal number of detectors shall be employed, and all reasonable efforts, consistent with safety, shall be made to locate them at the various places where the highest temperatures are likely to occur. See §**1002**.

Efficiency

2331* Efficiencies Recognized.—Two efficiencies are recognized, conventional efficiency and directly measured efficiency. Unless other-

(2321) Temperature by Resistance: The temperature by resistance may be calculated by the following formula:

Let r_t = resistance at t°C.

r_T = resistance at T°C.

Then $$T = \frac{r_T}{r_t}(234.5 + t) - 234.5$$

(2323) A coil side is one of the two active sides of the coil lying in a slot.

(2331) The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practically indeterminable, and must, in many cases, either be approximated by an approved method of test, or else values recommended by the Institute and designated "conventional" values shall be employed for themin arriving at the "conventional efficiency."

wise specified, the conventional efficiency is to be employed. See §§**3514** and **3524**.

Input and output determinations of efficiency may be made directly, measuring the output by brake, or equivalent, where applicable. Within the limits of practical application, the circulating power method, sometimes described as the Hopkinson or "loading-back" method, may be used.

2332* **Normal Conditions for Efficiency Tests.**—(*a*) *General*: The efficiency shall correspond to, or be corrected to, the normal conditions herein set forth, which shall be regarded as standard. These conditions include voltage, current, power-factor, frequency, wave-shape, speed, temperature, or such of them as may apply in each particular case.

(*b*) *Load*: When the efficiency of a machine is stated without specific reference to the load conditions, rated load is always to be understood whether the efficiency be the conventional or directly measured efficiency.

(*c*) *Wave Shape*: The sine wave shall be standard, unless a different wave form is inherent in the operation of the system. See §**2350**.

*(*d*) *Temperature of Reference*: The efficiency of all apparatus at all loads, shall be corrected to a reference temperature of 75° C, but tests may be made at any convenient ambient temperature, preferably not less than 15° C.

(*e*) *Power Factor*: The efficiency of alternators and transformers shall be stated at the rated power factor.

2333 **Direct Measurement of Efficiency.**—(*a*) *General*: Electric power shall be measured at the terminals of the apparatus.

(*b*) *Polyphase Machines*: In polyphase machines, sufficient measurements shall be made on all phases to avoid errors of unbalance.

(*c*) *Mechanical Power*: Mechanical power delivered by machines shall be measured at the pulley, gearing or coupling, on the rotor shaft, thus excluding the loss of power in the belt or gear friction. See, however, an exception in §**5202**.

Wave Shape.

2340 **Standard Wave Shape.**—The Sine Wave shall be considered as standard, except where departure therefrom is inherent in the operation of the system of which the electrical machine forms a part.

Tests of Dielectric Strength

2350 **Condition of Machine to be Tested.**—Commercial tests shall, in general, be made with the completely assembled machine and not with individual parts. The machine shall be in good condition, and high-voltage tests, unless otherwise specified, shall be applied

(2332 d) In calculating plant or system efficiency it may be desirable to calculate the losses in each individual machine or part of the system at the actual temperature of that transformer or part during the specified interval. These losses may be appreciably different from the losses at 75° C, which latter shall be the standard temperature of reference for all efficiency guarantees.

before the machine is put into commercial service, and shall not be applied when the insulation resistance is low due to dirt or moisture. High voltage tests to determine whether specifications are fulfilled are admissible on new machines only.

2351 Where High-Voltage Tests are to be Made.—Unless otherwise agreed upon, high-voltage tests of machines shall be made at the factory.

2352 Temperature at which High-Voltage Tests are to be made.—High-voltage tests shall be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial testing.

2353 Points of Application of Voltage.—(*a*) *General:* The test voltage shall be successively applied between each electric circuit and all other electric circuits and metal parts grounded.

(*b*) *Interconnected Polyphase Windings:* Interconnected polyphase windings shall be considered as one circuit. All windings except that under test shall be connected to ground.

2354 Frequency and Wave Shape of Test Voltage.—The frequency of the testing voltage shall be not less than the rated frequency of the machine tested. A sine wave shape is recommended, (see §§**2340** and **4351**). The test shall be made with alternating voltage having a crest value equal to $\sqrt{2}$ times the specified test voltage.

2355 Duration of Application of Test Voltage.—(a) *General:* The testing voltage for machines shall be applied continuously for a period of 60 seconds. See exception §**2355** (b).

(b) *Standard Machines and Devices produced in large quantities*: Standard machines and devices produced in large quantities for which the standard test pressure is 2500 volts or less, may be tested for one second with a test pressure 20 per cent higher than the one minute test pressure.

2356 Standard Test Voltage.—(a) *General:* The standard test voltage for all machines, except as otherwise specified, shall be twice the normal voltage of the circuit to which the machine is connected plus 1000 volts. See exceptions §§**2357, 4361, 6361.**

2357 Assembled Apparatus.—Where a number of pieces of apparatus are assembled together and tested as an electrical unit they shall be tested with 15 per cent lower voltage than the lowest required on any of the individual pieces of apparatus.

2358 Measurement of Voltage in Dielectric Strength Tests.—There are two methods of measuring the voltage used in making dielectric strength tests, namely

1. The voltmeter method.
2. The spark gap method, using either the sphere spark gap or the needle spark gap.

2359* Use of Voltmeters and Spark-gaps in Dielectric Tests.—When making high voltage tests on electrical machinery every precaution

(2359) The resistance will damp high frequency oscillations at the time of breakdown and limit the resulting current.

Carbon resistors should not be used because their resistance may become very low at high voltages.

must be taken against the occurrence of spark-gap discharges in the circuits from which the machine is being tested. A non-inductive resistance of about one ohm per volt of test pressure shall be inserted in series with one terminal of the spark gap. If the test is made with one electrode grounded, this resistance shall be inserted directly in series with the non-grounded electrode; if neither terminal is grounded one-half shall be inserted directly in series with each electrode. In either case this resistance shall be as near the measuring gap as possible and not in series with the tested apparatus. A water tube is the most suitable form of resistor.

2360 **Use of Spark-gap with Machines of Low Capacitance.**—When the machine under test does not require sufficient charging current to distort the high-voltage wave shape, or change the ratio of transformation, the spark-gap should be set for the required test voltage and the testing apparatus adjusted to give a voltage at which this spark-gap just breaks down. This adjustment should be made with the machine under test disconnected. The machine should then be connected, and with the spark-gap about 20 per cent longer, the testing apparatus again adjusted to give the voltage of the former breakdown, which is the assumed voltage of test. This voltage shall be maintained for the required interval.

2361* **Use of Spark-gap with machines of High Capacitance.**—When the charging current of the machine under test may appreciably distort the voltage wave or change the effective ratio of the testing transformer, the first adjustment of voltage with the gap set for the test voltage shall be made with the machine under test connected to the circuit and in parallel with the spark-gap.

2362 **Measurements with Voltmeter.**—In measuring the voltage with a voltmeter, the instrument should preferably derive its voltage from the high-pressure circuit, either directly, or by means of a voltmeter coil placed in the testing transformer, or through an auxiliary *ratio transformer*. It is permissible to measure the voltage at other places such as the transformer primary, provided corrections can be made for the variations in ratio caused by the charging current of the machine under test, or provided there is no material variation in this ratio. In any case when the capacitance of the machine to be tested is such as to cause wave distortion, the testing voltage must be checked by a spark gap as set forth in §§**2364** and **2366** or by a crest-voltage meter. If the crest-voltage meter is calibrated in crest volts, its readings must be reduced to the corresponding r. m. s. sinusoidal value by dividing by $\sqrt{2}$.

(2361) When making arc-over tests of large insulators, leads, etc. partial arc-over of the tested apparatus may produce oscillations which will cause the measuring gap to discharge prematurely. The measured voltage will then appear too high. In such tests the "equivalent ratio" of the testing transformer should be measured by gap to within 20 per cent of the arc-over voltage of the tested apparatus with the tested apparatus in circuit. The measuring gap should then be greatly lengthened out and the voltage increased until the tested apparatus arcs over. This arc-over voltage should then be determined by multiplying the voltmeter reading by the equivalent ratio found above. Direct measurement of the spark-over voltage over one gap by another gap should always be avoided.

2363 Measurements with Spark Gaps.—(*a*) *General:* If proper precautions are taken, spark gaps may be used to advantage in checking the calibration of voltmeters for high voltage tests of machines.

(*b*) *Range of Voltages:* For the calibrating purposes set forth above the sphere gap shall be used for voltages above 50 kv., and is preferred down to 30 kv. The needle spark gap may, however, be used for voltages from 10 to 50 kv.

2364 Needle Spark Gap.—The needle spark gap shall be between new sewing needles, supported axially at the ends of linear conductors, which are at least twice the length of the gap. There must be a clear space around the gap for a radius at least twice the gap length.

2365 Needle Gap Sparking Distances.—The sparking distances in air between No. 00 double long sewing needle points for various root-mean-square sinusoidal voltages shall be assumed to be as shown in Table 202.

TABLE 202

Needle-Gap Spark-Over Voltages

(At 25° C and 760 mm. barometer).

R. M. S. Kilovolts	Millimeters	R. M. S. Kilovolts	Millimeters
10	11.9	35	51
15	18.4	40	62
20	25.4	45	75
25	33	50	90
30	41		

The values in Table 202 refer to a relative humidity of 80 per cent, Variations from this humidity may involve appreciable variations in the sparking distance.

2366* Sphere Spark-Gap.—The standard sphere spark gap shall be between two suitably mounted spheres. No extraneous body, or external part of the circuit, shall be nearer the spheres than twice their diameter.

The shanks shall be not greater in diameter than $^{1}/_{5}$th the sphere diameter. Metal collars etc., through which the shanks extend, shall be as small as practicable and shall not, during any measurement, come closer to the sphere than the maximum gap length used in the measurement.

The sphere diameter should not vary more than 0.1 per cent, and the curvature, measured by a spherometer, should not vary more than 1 per cent from that of a true sphere of the required diameter.

(2366) When used as specified, the accuracy obtainable should be approximately 2 per cent.

2367* **Use of Spherometer.**—In using the spherometer to measure curvature, the distance between the points of contact of the spherometer feet shall be within the limits as indicated in Table 203.

TABLE 203

Spherometer Specifications

Diameter of sphere in. mm.	Distance between contact points in mm.	
	Maximum	Minimum
62.5	35	25
125	45	35
250	65	45
500	100	65

2368 **Sphere-Gap Sparking Distances.**—The sparking distance between spheres for various r. m. s. sinusoidal voltages shall be assumed to be as shown in Table 204.

2369* **Correction of Gap Spacing for Air-Density.**—The spacing at which it is necessary to set a gap to spark over at some required voltage, is found as follows. Divide the required voltage by the correction factor given in Table 205 and use the new voltage thus obtained, to find the corresponding spacing from Table 204, using a graph of the latter, if more convenient.

2370* **Correction of Voltage for Air-Density.**—The voltage at which a gap sparks over is derived from the voltage corresponding to the spacing in Table 204 by multiplying by the correction factor.

(2367) In using sphere gaps constructed as indicated in §**2366** and §**2367**, it is assumed that the apparatus will be set up for use in a space comparatively free from external dielectric fields. Care should be taken that conducting bodies forming part of the circuit, or at circuit potential, are not so located with reference to the gap that their dielectric fields are superposed on the gap, *e. g.*, the protecting resistance should not be arranged so as to present large masses or surfaces near the gap, even at a distance of two sphere diameters.

In case the sphere is grounded, the spark point of the grounded sphere should be approximately five diameters above the floor or ground.

(2369 and 2370) Effect of Air Density on Spark-Over Voltage. The spark-over voltage, for a given gap, decreases with decreasing barometric pressure and increasing temperature. This variation may be considerable at high altitudes. When the variation from sea level is not great, the relative air density may be used as the correction factor; when the variation is great, or greater accuracy is desired, the correction factor corresponding to the relative air density should be taken from Table 204 in which

$$\text{Relative air density} = \frac{0.392\, b}{273 + t}$$

b = barometric pressure in mm.
t = temperature in deg. C.

Corrected curves may be plotted for any given altitude, if desired. It will be noted in Table 213 that for values of relative air density above 0.9 the correction factor does not differ greatly from the relative air density.

TABLE 204

Sphere-Gap Spark-Over Voltages

(At 25°C and 760 mm. barometric pressure)

Kilo-volts	Sparking Distance in Millimeters.							
	62.5 mm. spheres		125 mm. spheres		250 mm. spheres		500 mm. spheres	
	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated
10	4.2	4.2	..	..	..	..	..	..
20	8.6	8.6	..	..	..	..	..	..
30	14.1	14.1	14.1	14.1	..	..	..	..
40	19.2	19.2	19.1	19.1	..	..	..	..
50	25.5	25.0	24.4	24.4	..	..	..	..
60	34.5	32.0	30.	30.	29	29	..	..
70	46.0	39.5	36	36	35	35	..	..
80	62.0	49.0	42	42	41	41	41	41
90		60.5	49	49	46	45	46	45
100			56	55	52	51	52	51
120			79.7	71	64	63	63	62
140			108	88	78	77	74	73
160			150	110	92	90	85	83
180				138	109	106	97	95
200					128	123	108	106
220					150	141	120	117
240					177	160	133	130
260					210	180	148	144
280					250	203	163	158
300						231	177	171
320						265	194	187
340							214	204
360							234	221
380							255	239
400							276	257

The sphere gap is more sensitive than the needle gap to momentary rises of voltage and the voltage required to spark over the gap should be obtained by slowly closing the gap under constant voltage, or by slowly raising the voltage with a fixed setting of the gap. Open arcs should not be permitted in proximity to the gap during its operation, as they may affect its calibration.

Table 205

Air Density Correction Factors for Sphere Gaps.

Relative air density	Diameter of standard spheres in mm.			
	62.5	125	250	500
0.50	0.547	0.535	0.527	0.519
0.55	0.594	0.583	0.575	0.567
0.60	0.640	0.630	0.623	0.615
0.65	0.686	0.677	0.670	0.663
0.70	0.732	0.724	0.718	0.711
0.75	0.777	0.771	0.766	0.759
0.80	0.821	0.816	0.812	0.807
0.85	0.866	0.862	0.859	0.855
0.90	0.910	0.908	0.906	0.904
0.95	0.956	0.955	0.954	0.952
1.00	1.000	1.000	1.000	1.000
1.05	1.044	1.045	1.046	1.048
1.10	1.090	1.092	1.094	1.096

Insulation Resistance

2380 General.—The insulation resistance test shall be made with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltage above ground shall be tested separately.

2381 Voltage for Insulation Resistance Test.—Insulation resistance tests shall, if possible, be made at a d-c. pressure of 500 volts. Since the insulation resistance varies with the pressure, it is necessary that, if a pressure other than 500 volts is to be employed in any case, this other pressure shall be clearly specified.

2382* Minimum Values.—The insulation resistance of a machine at its

(2382) The order of magnitude obtained by this rule is shown in the following table.

TABLE 206

Insulation Resistance of Machines Excluding Oil-Immersed Apparatus.

Rated voltage of machine	Megohms		
	100 kv-a.	1000 kv-a.	10,000 kv-a.
100	0.091	0.05	—
1,000	0.91	0.50	0.091
10,000	9.1	5.0	0.91
100,000	—	50	9.1

operating temperature shall be not less than that given by the following formula:

$$\text{Insulation Resistance in megohms} = \frac{\text{voltage at terminals}}{\text{rating in kv-a.} + 1000}$$

The formula applies only to dry apparatus. Such high values are not attainable in oil-immersed apparatus.

Regulation

2390 Conditions for Tests of Regulation.—(a) *Speed and Frequency:* The regulation of generators shall be determined at constant speed, and that of alternating current machines at constant frequency.

(*b*) *Wave Form:* A sine wave of voltage shall be assumed in determining the regulation of alternating current machinery receiving electric power, except where expressly specified otherwise. See §2340.

(*c*) *Temperature*: It is desirable that all parts of the machine affecting the regulation be maintained at constant temperature between the two loads and where the influence of temperature is of consequence, a reference temperature of 75° C. shall be considered as standard. If change of temperature should occur during the tests the results shall be corrected to the reference temperature of 75° C.

CONSTRUCTION

Rating Plates

2401 Marking of Rating Plate.—(a) *Distinctive Marking*: It is recommended that the rating plate of machines which comply with the Institute Rules shall carry a distinctive special sign, such as "A.I.E.E. 1920 Rating" or "A20" Rating.

(b) *Significance of Marking*: The absence of any statement to the contrary on the rating plate of a machine implies that it is intended for continuous service and for the standard altitude and ambient temperature. See §§**2211**, **2212**, **2215**, and **2220**.

(c) *Marking for Various Ratings*: The rating plate of a machine intended to work under various kinds of rating must carry the necessary information in regard to those kinds of ratings.

CHAPTER III.

GENERAL DEFINITIONS

In this chapter are given definitions which are of general application to electric circuits, machines and systems. Definitions pertaining to a specific class of apparatus are given in the chapter on the class of apparatus in question. The definitions here given are primarily descriptive rather than scientifically precise.

The definitions given below for currents are also applicable, in most cases, to electromotive forces, potential differences, magnetic fluxes, etc.

DEFINITIONS

General

3000 **Ambient Temperature.**—The ambient temperature is the temperature of the air or water which comes into contact with the heated parts of a machine and carries off its heat. See §§**2300** and **2301.**

Resistivity

3020 **Resistivity.**—The resistivity of a material is the resistance expressed in ohms between two opposite faces of a centimeter cube of the material, and is usually coupled with a statement of the temperature. See §**9050.**

Apparatus

3064 **Resistor.**—A resistor is a device used primarily because it possesses the property of electrical resistance. Resistors are used in electric circuits for purposes of operation, protection, or control. See §**7018.**

3070 **Inductor.**—An inductor is a device used primarily because it possesses the property of inductance.

3078 **Reactor.**—A reactor is a device used primarily because it possesses the property of reactance. Reactors are used in electric circuits for purposes of operation, protection or control.

Kinds of Currents

3104 **Direct Current.**—A direct current is a unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

3108 **Pulsating Current.**—A pulsating current is a current which has regularly recurring variations in magnitude. As ordinarily employed the term refers to a unidirectional current.

3112 **Continuous Current.**—A continuous current is a practically non-pulsating direct current.

3116 Alternating Current.—An alternating current is a current the direction of which reverses at regularly recurring intervals. Unless distinctly otherwise specified, the term *alternating current* refers to a periodically varying current with successive half waves of the same shape and area. See §**3212**

3120 Oscillating, or Free Alternating-Current.—An oscillating, or free alternating-current is the current following any electro-magnetic disturbance in a circuit having capacity, inductance, and less than the critical resistance. When the critical resistance of a circuit is reached the current becomes aperiodic.

Alternating Currents

3204 Cycle.—A cycle is one complete set of positive and negative values of an alternating current.

3206 Period.—The period of an alternating current is the time required for the current to pass through one cycle.

3208 Frequency.—The frequency of an alternating current is the number of cycles through which it passes per second, that is, the reciprocal of the period.

3212 Wave Shape.—The wave shape, or wave form, of an alternating current is the shape of the curve obtained when the instantaneous values of the current are plotted against time in rectangular co-ordinates.

Two alternating quantities are said to have the same wave shape when their ordinates of corresponding phase bear a constant ratio to each other. The wave shape, as thus understood, is therefore independent of the frequency of the current and of the scale to which the curve is plotted.

3214 Sine-Wave, or Simple Alternating-Current.—A sine wave, or simple alternating-current is a current whose wave shape is sinusoidal.

3218* Root-Mean-Square or **Effective Value.**—The root-mean-square or effective value of an alternating current is the square root of the mean of the squares of the instantaneous values for one complete cycle. It is usually abbreviated r. m. s. Unless otherwise specified, the numerical value of an alternating current refers to its r. m. s. value. The word "virtual" is sometimes used in place of r. m. s., particularly in Great Britain.

3222 Phase.—Phase is the fraction of the period of an alternating current which has elapsed since the current passed through the zero position of reference.

This fraction is usually expressed in angular measure, and the period corresponding to one complete cycle is taken as representing 2π radians or 360 degrees. The angles are frequently called electric angles, and the degrees electric degrees.

(3218) The r. m. s. value of a sine wave (see Section 3214) is equal to its maximum, or crest value, divided by $\sqrt{2}$.

In the usual equation

$$i = I_m \sin(\omega t + \varphi)$$

the quantity $(\omega t + \varphi)$ is the phase and φ is the phase angle of the current.

3224* Phase Difference; Lead and Lag.—The phase difference of two alternating quantities of the same frequency is the difference between their phases at any instant. That quantity whose maximum occurs first in time is said to lead the other, and the latter is said to lag behind the former.

3228 Vector Representation and Angular Velocity.—A sine-wave current or voltage may be represented by a vector of constant length rotating counter-clockwise at a constant angular velocity ($\omega = 2\pi f$); this angular velocity is frequently termed the angular velocity of the current or voltage.

3230* Counter-clockwise Convention.—It is recommended that, in any vector diagram, the leading vector be drawn counter-clockwise with respect to the lagging vector, as in Fig. 3—1 where $O\ I$ represents the vector of a current in a simple alternating current circuit lagging behind the vector $O\ E$ of impressed electromotive force.

FIG. 3-1

3234 Power.—Power is the rate of transfer of energy. In the case of an alternating-current circuit the word power is generally used to denote the average value of the power over a cycle. The power in an electric circuit at any instant is equal to the product of the values of the current and voltage at that instant, and is generally called the instantaneous power.

3238 Apparent Power or Volt-amperes.—The apparent power, or volt-amperes, in an alternating current circuit is the product of the r. m. s. value of the voltage across the circuit by the r. m. s. value of the current in the circuit. Apparent power is also expressed in kilo-volt-amperes, abbreviated kv-a.

3242* Power Factor.—Power factor is the ratio of the power to the apparent power.

3246* Reactive Volt-amperes.—The reactive volt-amperes in a circuit is the square root of the difference between the square of the apparent power and the square of the power.

3250* Reactive Factor.—The reactive factor is the ratio of the reactive volt-amperes to the total volt-amperes.

(3224) When the two alternating quantities do not have the same wave form, the phase-difference as here defined may not be identical with equivalent phase-difference as defined in Section 3262.

(3230) See Publication 12 of the International Electrotechnical Commission (Report of Turin meeting, Sept. 1911, p. 78.)

(3242) The power factor when both the current and voltage are sinusoidal is equal to the cosine of the angle which expresses their difference in phase (see Section 3224).

(3246) The reactive volt-amperes, when both current and voltage are sinusoidal, is equal to the volt-amperes times the sine of the angle which expresses the phase difference between current and voltage.

(3250) The reactive factor, when both current and voltage are sinusoidal, is equal to the sine of the angle which expresses their phase difference.

3254* **Active Component.**—The active component of the current in a circuit is the average power divided by the voltage.

3256* **Reactive Component.**—The reactive component of the current in a circuit is the square root of the difference between the square of the current and the square of the active component of the current.

3260 **Equivalent Sine Wave.**—An equivalent sine wave is a sine wave which has the same frequency and the same r. m. s. value as the actual wave.

3262 **Equivalent Phase Difference.**—The equivalent phase difference (applicable to non-sinusoidal currents and voltages) is the phase difference between the equivalent sine waves of current and voltage when so related as to have the same power factor as the non-sinusoidal quantities.

There are cases, however, where this equivalent phase difference is misleading, since the presence of harmonics in the voltage wave, current wave, or in both, may reduce the power factor without producing a corresponding displacement of the two wave forms with respect to each other; *e. g.*, the case of an a-c. arc. In such cases, the components of the equivalent sine waves, the equivalent reactive factor and the equivalent reactive volt-amperes may have no physical significance.

3266* **Crest Factor or Peak Factor.**—The crest factor or peak factor of a wave is the ratio of the crest, or maximum, value to the r. m. s. value.

3270* **Form Factor of a Wave.**—The form factor of a wave is the ratio of the r. m. s. to the algebraic mean ordinate taken over a half cycle beginning with the zero value. If the wave passes through zero more than twice during a single cycle, that zero shall be taken which gives the largest algebraic mean for the succeeding half-cycle.

3274 **Deviation Factor of a Wave.**—The deviation factor of a wave is the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superposed in such a way as to make this maximum difference as small as possible.

3278 **Telephone Interference Factor of a Wave.** (See §**4352**)—The telephone interference factor is the ratio of the square root of the sum of the squares of the weighted values of all the sine wave components (including in alternating waves both fundamental and harmonics) to the r. m. s. value of the wave.

(3254) The active, or in-phase component of the current in a circuit corresponds to average power passing in a given direction through the circuit. With sine wave voltage and current, the active component of the current is in phase with the voltage.

(3256) The reactive, or quadrature, component of the current in a circuit corresponds to power alternating in direction in the circuit so that the average value of the power transferred in a given direction through a cycle is zero. With sine wave current and voltage the reactive component of the current is in quadrature with the voltage.

(3266) The crest factor of a sine wave is $\sqrt{2}$.

(3270) The form factor of a sine wave is $\frac{\pi}{2\sqrt{2}}$ or 1.11.

Circuits and Phases

3304 Electric Circuit.—An electric circuit is a path in which an electric current may flow. Strictly speaking, an electric circuit is a complete circulatory path, but the term circuit is commonly employed to designate a specific part of a complete path. When part of a complete path is referred to, such as a branch circuit, a derived circuit, or a conductor, both the terminals and the conductor which form that path should be specified in order to avoid ambiguity; *e. g.*, the circuit *a-b-c*. When the whole circuit is referred to, it may be designated as a complete or closed circuit.

3324* Single-Phase Circuit.—A single-phase circuit is a circuit energized by a single alternating electromotive force.

3326* Three-Phase Circuit.—A three-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase by one-third of a cycle; *i. e.*, 120 degrees.

3328* Quarter-Phase or Two-Phase Circuit.—A quarter-phase or two-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase by a quarter of a cycle; *i. e.*, 90 degrees.

3330* Six-Phase Circuit.—A six-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase by one sixth of a cycle; *i. e.*, 60 degrees.

3332 Polyphase Circuit.—A polyphase circuit is a circuit of more than a single phase. This term is ordinarily applied to symmetrical systems.

3344 Symmetrical Voltages and Currents.—Polyphase voltages or currents are symmetrical when the voltages or currents have the same wave shape and r. m. s. value and differ in phase each from the next by the same angle.

3348 Symmetrical Polyphase System.—A symmetrical polyphase system is a polyphase system in which the voltages are symmetrical.

3352* Balanced Polyphase System.—A balanced polyphase system is a polyphase system in which both the currents and voltages are symmetrical.

Loads

3404 Reactive Load.—A reactive load is a load in which the current lags behind or leads the voltage across the load.

(3324) A single-phase circuit is usually supplied through two wires. The currents in these two wires, counted outwards from the source, differ in phase by 180 degrees or a half cycle.

(3326) In practise the phases may vary several degrees from the specified angle.

(3328) In practise the phases may vary several degrees from the specified angle.

(3330) In practise the phases may vary several degrees from the specified angle.

(3352) The term balanced polyphase system is applied also to a quarter-phase (or two-phase) system in which the voltages have the same wave form and r. m. s. value and in which the currents have the same wave form and r. m. s. value and differ in phase by ninety electrical degrees.

3406 **Non-reactive Load.**—A non-reactive load is a load in which the current is in phase with the voltage across the load. (The term non-inductive load is sometimes used for non-reactive load.)

3408 **Inductive Load.**—An inductive load is a reactive load in which the current lags behind the voltage across the load.

3410 **Condensive Load.**—A condensive load is a reactive load in which the current leads the voltage across the load.

3414* **Balanced Polyphase Load.**—A balanced polyphase load is a load to which symmetrical currents are supplied when it is connected to a system having symmetrical voltages.

3424 **Connected Load.**—The connected load on any system, or part of a system, is the combined continuous rating of all the receiving apparatus on consumers' premises which is connected to the system, or part of the system under consideration.

3434 **Peak Power.**—The peak power is the average power during a time interval of specified duration occurring within a given period of time, that interval being selected during which the average power is greatest.

3438 **Load Factor.**—The load factor is the ratio of the average power to the peak power.

In each case, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load factor. The proper interval and period are usually dependent upon local conditions and upon the purpose for which the load factor is to be used.

3442 **Plant Factor.**—The plant factor is the ratio of the average load to the rated capacity of the power plant; *i. e.*, to the aggregate ratings of the generators.

3454 **Demand of an Installation or System.**—The demand of an installation or system is the load which is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time. Demand is expressed in kilowatts, kilovolt-amperes, amperes, or other suitable units.

3458 **Maximum Demand.**—The maximum demand of an installation or system is the greatest of all the demands which have occurred during a given period. It is determined by measurement, according to specifications, over a prescribed time interval.

3460 **Demand Factor.**—The demand factor of any system or part of a system, is the ratio of the maximum demand of the system, or part of a system, to the total connected load of the system, or of the part of the system under consideration.

3464 **Diversity Factor.**—The diversity factor of any system, or part of a system, is the ratio of the sum of the maximum power demands

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(3414) The term balanced polyphase load is applied also to a load to which are supplied two currents having the same wave form and r. m. s. value and differing in phase by ninety electrical degrees when it is connected to a quarter-phase (or two-phase) system having voltages of the same wave form and r. m. s. value.

of the subdivisions of the system, or part of a system, to the maximum demand of the whole system, or part of the system under consideration, measured at the point of supply.

Machinery and Apparatus

3504 **Capacity (or Properly, Capability).**—The word "capacity" is frequently used in the general sense of "capability". It is also used in a more exact sense to denote the load which, when carried by a machine, apparatus, or device will, under specified conditions of test, cause it to reach *any one of its physical limitations*, such for example, as operating temperature or ability to maintain required voltage.

Capacity should be distinguished from rating. On account of the different senses in which it has been employed (see §**3508**), capacity is less used than it formerly was, rating being more useful commercially.

3508* **Rating.**—A rating of a machine, apparatus or device is an arbitrary designation of an operating limit.

(The rating of a machine is the output marked on the rating plate, and shall be based on, but shall not exceed the maximum load which can be taken from the machine under prescribed conditions of test. This is also called the rated output. *Maximum possible rating obviously corresponds with capability as defined in §3504*).

3514 **Efficiency.**—The efficiency of an electric machine or apparatus is the ratio of its useful output to its total input. Unless otherwise specified the above output and input shall mean the power output and the power input respectively.

3524* **Conventional Efficiency.**—The conventional efficiency of an electric machine or apparatus is the ratio of the output to the sum of the output and the losses, or of the input minus the losses to the input, when, in either case conventional values are assigned to one or more of these losses.

3534 **Plant, or System, Efficiency.**—Plant, or system, efficiency is the ratio of the energy delivered from the plant or system to the energy received by it in a specified period of time. In calculating plant, or system, efficiency it may be desirable to calculate the losses in each individual machine, or part of the system, at the actual temperature of that machine, or part, during the specified interval. These losses may be appreciably different from the losses at 75° C., which latter shall be the standard temperature of reference for all efficiency guarantees. This definition is not applicable to storage batteries. See §**2332**.

3535 **Regulation.**—The regulation of a machine in regard to some characteristic quantity (such as terminal voltage or speed) is

(3508) The term maximum load does not refer to loads applied solely for mechanical, commutation, or similar tests.

(3524) The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electric machinery are practically indeterminable, and must, in many cases, either be approximated by an approved method of test, or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "conventional efficiency."

the change in that quantity occurring between any two loads. Unless otherwise specified, the two loads considered shall be zero load and rated load, and at the temperature attained under normal operation. The regulation may be expressed by stating the numerical values of the quantity at the two loads, or it may be expressed by the "percentage regulation", which is the percentage ratio of the change in the quantity occurring between the two loads, to the value of the quantity at either one or the other load, taken as the normal value. The normal value may be either the no-load value, as the no-load speed of induction motors; or it may be the rated-load value, as in the voltage of a-c. generators.

It is assumed that all parts of the machine affecting the regulation maintain constant temperature between the two loads, and where the influence of temperature is of consequence a reference temperature of 75° C. shall be considered as standard.

TABLE 301.

3604* **SYMBOLS AND ABBREVIATIONS**

Name of Quantity.	Symbol for the Quantity.	Unit.	Abbreviation for the Unit.
Acceleration due to gravity	g	centimeter per second per second	cm. per sec. per sec.
Admittance	Y, y	mho	....
Angular velocity	ω	radian per second	....
Capacitance (Electrostatic capacity)	C	farad	....
Conductance	g	mho	....
Conductivity	γ	*mho per centimeter	mho per cm.
Current	I, i	ampere	....
Dielectric constant	K	....	....
Efficiency	η	per cent	....
Electromotive force, abbreviated e. m. f.	E, e	volt	....
Electrostatic field intensity	F	....	....
Electrostatic flux	Ψ	....	....
Electrostatic flux density	D	....	....
Energy, in general	U or W	joule, watt-hour	....
Frequency	f	cycle per second	~
Impedance	Z, z	ohm	....
Inductance (or coefficient of self induction)	L	henry	....
Intensity of magnetization	J	....	....
Length	l	centimeter	cm.
Magnetic field intensity	H, $\mathcal{H}$	gilbert per centimeter or gauss*	gilbert per cm. ....
Magnetic flux	Φ, φ	maxwell	....
Magnetic flux density	B, $\mathcal{B}$	gauss	....

Magnetomotive force, abbreviated m. m. f.	$\mathfrak{F}$	gilbert*	....
Mass	m	gram	g
Mutual Inductance (or coefficient of mutual induction)	M	henry	....
Number of conductors or turns	N	convolution or turn of wire	....
Permeability	$\mu = B/H$	....	
Phase displacement	θ, φ	degree or radian	° ....
Potential difference, abbreviated p. d.	V, v or E, e	volt	....
Power	P, p	watt	....
Quantity of electricity	Q, q	coulomb, ampere-hour	....
Reactance	X, x	ohm	....
Reluctance	$\mathfrak{R}$	....	....
Resistance	R, r	ohm	....
Resistivity	ρ	* ohm-centimeter	ohm-cm.
Standard acceleration due to gravity (at about 45 deg. latitude and sea level) equals 980.665*	g_0	centimeter per second per second	cm. per sec. per sec.
Susceptance	b	mho	....
Susceptibility	$\kappa = J/H$	....	....
Temperature	θ	degree centigrade	°C
Time	t	second	sec.
Velocity of rotation	n	revolution per second	rev. per sec.
Voltage	E, e or V, v	volt	....

3608 Symbols for Maximum, Instantaneous and R. M. S. Values.— E_m, I_m and P_m should be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r. m. s. values (see §**3218**) and P for the average value of the power, or the active power. These distinctions are not necessary in dealing with direct-current circuits. In print, vector quantities should be represented by boldface capitals.

BIBLIOGRAPHY

Associazione Elettrotecnica Italiana: Simboli e Notazioni.

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(3604) The gauss is provisionally accepted for the present as the name of both the unit of field intensity and flux density, on the assumption that permeability is a simple numeric.

An aditional unit for magnetomotive force is the "ampere-turn", for flux the "line", for magnetic flux-density "maxwells per sq. in.".

The numerical values of resistivity and conductivity are *ohms resistance* and *mhos conductance* between two opposite faces of a cm. cube of the material in question,. but the correct names are as given, not ohms and mhos per cm, cube, as commonly stated

The value 980.665 for g_0 has been the accepted standard value for many years and was formerly considered to correspond accurately to 45° latitude and sea level. Later researches, however, have shown that the most reliable value for 45° and sea-level is slightly different; but this does not affect the standard value given above.

CHAPTER IV.

STANDARDS FOR ROTATING MACHINES (OTHER THAN RAILWAY MOTORS, RAILWAY SUBSTATION MACHINERY CARRYING TRACTION LOADS, AND AUTOMOBILE PROPULSION MACHINES).

The A. I. E. E. Standards for Rotating Machines are the General Standards shown in Chapters II and III and the Standards in other chapters which are applicable to the devices involved, together with the modifications and extensions given in this chapter.

DEFINITIONS

General.

Certain rules applying exclusively to railway machinery have, for convenience, been placed in Chapter V, with cross references in all cases in this chapter. The rules of Chapter IV apply to railway machinery except as they are modified by rules of Chapter V.

4000 **Classification of Electric Rotating Machinery.**—Rotating electric machinery may be classified in various ways, these classifications over-lapping or interlocking in considerable degree. *First*, Rotating electric machinery may be classified as Direct-Current and Alternating-Current; *Second*, according to the function of the machines; *e. g.*, Motors, Generators, Boosters, Motor-Generators, Dynamotors, Double-Current Generators, Converters and Phase Advancers; *Third*, according to construction or principle of operation; *e. g.*, Commutating, Synchronous, Induction, Unipolar, Rectifying. Obviously, some of these machines could be rationally included in either classification, *e. g.*, Motor-Generators and Rectifying Machines.

In the following, self-evident definitions have for the most part been omitted.

Functional Classification of Rotating Electric Machines.

4001 **Generator.**—A generator is a machine which transforms mechanical power into electric power.

4002 **Motor.**—A motor is a machine which transforms electric power into mechanical power.

4003 **Booster.**—A booster is a generator inserted in series in a circuit to change its voltage. A booster may be driven by an electric motor (in which case it is termed a motor-booster) or otherwise.

4004 **Motor-Generator Set.**—A motor-generator set is a transforming device consisting of one or more motors mechanically coupled to one or more generators.

4005 **Dynamotor.**—A dynamotor is a transforming device combining both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings and independent commutators.

4006 **Direct-Current Compensator or Balancer.**—A direct current compensator or balancer is a machine which comprises two or more similar direct-current machines (usually with shunt or compound excitation) directly coupled to each other and connected in series across the outer conductors of a multiple-wire system of distribution, for the purpose of maintaining the potentials of the intermediate wires of the system, which are connected to the junction points between the machines.

4007 **Double-Current Generator.**—A double-current generator is a machine which supplies both direct and alternating currents from the same armature-winding.

4008 **Converter.**—A converter is a machine which employs mechanical rotation in changing electric energy from one form into another. There are several types of converters, as defined in §§ **4009** to **4013** below.

4009 **Direct-Current Converter.**—A direct-current converter is a machine which converts from a direct current to a direct current, usually with a change of voltage. Such a machine may be either a motor-generator set or a dynamotor.

4010 **Synchronous Converter.**—A synchronous converter (sometimes called a rotary converter) is a machine which converts from an alternating to a direct current, or vice-versa. It is a synchronous machine with a single closed-coil armature winding, a commutator and slip rings.

4011 **Cascade Converter.**—A cascade converter (also called a motor converter) is a combination of an induction motor with a synchronous converter, the secondary circuit of the former feeding directly into the armature of the latter; *i. e.*, a synchronous converter concatenated with an induction motor.

4012 **Frequency Converter.**—A frequency converter is a machine which converts the power of an alternating-current system from one frequency to another, with or without a change in the number of phases, or in the voltage.

4013 **Rotary Phase-Converter.**—A rotary phase-converter is a machine which converts from an alternating-current system of one or more phases to an alternating-current system of a different number of phases, but of the same frequency.

4014 **Phase Advancer.**—A phase advancer is a machine which supplies reactive volt-amperes to the system to which it is connected. Phase advancers may be either synchronous or asynchronous.

4015 **Synchronous Condenser or Synchronous Phase Advancer.**—A synchronous condenser or synchronous phase advancer is a synchronous machine, running either idle or with load, the field ex-

citation of which may be varied so as to modify the power factor of the system, or through such modification to influence the load voltage.

Constructional Classification of Rotating Electric Machines

4016 **Direct-Current Commutating Machines.**—A direct current commutating machine comprises a magnetic field of constant polarity, an armature, and a commutator connected therewith. Specific types of direct-current commutating machines are: Direct-Current Generators; Direct-Current Motors; Direct-Current Boosters; Direct-Current Motor-Generator Sets and Dynamotors; Direct-Current Compensators or Balancers; and Arc Machines.

4017 **Alternating-Current Commutating Machine.**—An alternating current commutating machine comprises a magnetic field of alternating polarity, an armature, and commutator connected therewith. See §§ **4071** to **4074**.

4018 **Synchronous Commutating Machine.**—Synchronous commutating machines include synchronous converters, cascade-converters, and double-current generators.

4019 **Synchronous Machine.**—A synchronous machine comprises a constant magnetic field and an armature receiving or delivering alternating-currents in synchronism with the motion of the machine; *i. e.*, having a frequency strictly proportional to the speed of the machine. Specific types of synchronous machines are defined in §§ **4020** to **4023** below.

4020 **Alternator.**—An alternator is a synchronous alternating-current generator, either single-phase or polyphase.

4021 **Polyphase Alternator.**—A polyphase alternator is a polyphase synchronous alternating-current generator, as distinguished from a single-phase alternator.

4022 **Inductor Alternator.**—An inductor alternator is an alternator in which both field and armature windings are stationary, and in which masses of iron or inductors, by moving past the coils, alter the magnetic flux through them. It may be either single-phase or polyphase.

4023 **Synchronous Motor.**—A synchronous motor is a machine structurally identical with an alternator, but operated as a motor.

4024 **Induction Machine.**—An induction machine is a machine wherein primary and secondary windings rotate with respect to each other; *e. g.*, induction motors, induction generators, certain types of frequency converters and certain types of rotary phase-converters.

4025 **Induction Motor.**—An induction motor is an alternating-current motor, either single-phase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding receives power from the primary by electromagnetic induction.

4026 **Induction Generator.**—An induction generator is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

4027 **Engine Type Generator.**—An engine type generator is one coupled to an engine in such a way that it cannot be run independently of the engine.

4028 **Unipolar or Acyclic Machine.**—A unipolar, or acyclic machine, is a direct-current machine, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

Speed Classification of Motors.

4035 **Constant-Speed Motor.**—A constant speed motor is one whose speed is either constant or does not materially vary; such as a synchronous motor, an induction motor with small slip, and an ordinary direct-current shunt motor.

4036 **Multispeed Motor (or Change Speed Motor).**—A multispeed motor is a motor which can be operated at any one of several distinct speeds (these speeds being practically independent of the load), but which cannot be operated at intermediate speeds.

4037 **Adjustable-Speed Motor.**—An adjustable-speed motor is one in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load; such as a shunt motor designed for a considerable range of speed variation.

4038 **Base Speed of an Adjustable-Speed Motor.**—The base-speed of an adjustable-speed motor is that speed of the motor obtained with full field under full load with no resistor in the armature circuit.

4039 **Varying-Speed Motor.**—A varying speed motor is one whose speed varies with the load, ordinarily decreasing when the load increases; such as a series motor, a compound-wound motor, and a series-shunt motor. As a subclass of varying-speed motors, may be cited adjustable varying-speed motors, or motors in which the speed can be varied over a considerable range at any given load, but when once adjusted, varies with the load; *e. g.*, compound-wound motors arranged for adjustment of speed by varying the strength of the shunt field.

Classification of Rotating Electric Machines Relative to their Degree of Enclosure.

4041 **Open Machine.**—An open machine is of either the pedestal-bearing or end bracket type where there is no restriction to ventilation, other than that necessitated by good mechanical construction.

4042 **Protected Machine.**—A protected machine is one in which the armature, field coils, and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.

4043 **Enclosed Ventilated Machine.**—An enclosed ventilated (or semi-enclosed) machine is one in which the ventilating openings in the frame are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures not exceeding ½ square inch (3.2 sq. cm.) in area. See §**4316**.

4044 **Totally Enclosed Machine.**—A totally enclosed machine is one so enclosed as to prevent circulation of air between the inside and the outside of the case, but not sufficiently to be termed air-tight.

4045 **Separately Ventilated Machine.**—A separately ventilated machine has its ventilating air supplied by an independent fan or blower external to the machine.

4046 **Self-Ventilated Machine.**—A self-ventilated machine differs from a separately ventilated machine only in having its ventilating air circulated by a fan, blower, or centrifugal device integral with the machine.

If the heated air expelled from the machine is conveyed away through a pipe attached to the machine, this should be so stated.

4047 **Water-Cooled Machine.**—A water-cooled machine is one which mainly depends on water circulation for the removal of its heat.

4048 **Drip-Proof Machine.**—A drip-proof machine is one so protected as to exclude falling moisture or dirt. A drip proof machine may be either open or semi-enclosed, if it is provided with suitable protection integral with the machine, or so enclosed as to exclude effectively falling solid or liquid material.

4051 **Explosion-Proof Machine (or Flame-Proof Machine).**—An explosion-proof machine is a machine in which the enclosing case can withstand, without injury, any explosion of gas that may occur within it, and will not transmit the flame to any inflammable gas outside it.

4052 **Machine with Explosion-Proof Slip-Ring Enclosure.**—A machine in which the slip rings and brushes alone are included within an explosion-proof case should not be described as an explosion-proof machine, but as a machine with explosion-proof slip-ring enclosure.

Classification of Alternating-Current Commutator Motors.

(An alternating current commutator motor may be classified under more than one of the following groups.)

Classification by Phases of Energy Supply.

4061 **Single-Phase Commutator Motor.**—A single-phase commutator motor is one that receives the whole of its energy from only one phase of an alternating-current supply system, without requiring external phase-converting apparatus.

4062 **Polyphase Commutator Motor.**—A polyphase commutator motor is one that receives its energy from a plurality of phases of an alternating-current supply system, or from a single-phase system through phase-converting apparatus external to the motor.

Classification by Speed Characteristics.

4063 General.—For convenience, alternating-current commutator motors may be classified with reference to their speed characteristics as (1) constant-speed motors, (2) multi-speed motors, (3) adjustable-speed motors, and (4) varying-speed motors. Definitions of these terms as given in §§ **4035** to **4039** for motors in general, should be adopted for alternating-current commutator motors, in so far as they are applicable.

Classification by Excitation.

4064 Stator-Excited Commutator Motor.—A stator-excited commutator motor is one in which the torque-producing field is due to a current in a winding located on the stator. By the "torque producing field" is meant that component of the magnetic field which, with the in-phase component of the current, produces the torque of the motor.

4065 Rotor-Excited Commutator Motor.—A rotor-excited commutator motor is one in which the torque-producing field is due to a current in a winding located on the rotor. See §**4064**.

4066 Stator- and Rotor-Excited Commutator Motor.—A stator- and rotor-excited commutator motor is one in which the torque producing field is due to currents in windings located on the stator and on the rotor. See §**4064**.

4067* Constant-Field Commutator Motor.—A constant-field commutator motor is one in which the torque-producing field remains practically constant, independent of the load. See §**4064**.

4068* Varying-Field Commutator Motor.—A varying-field commutator motor is one in which the torque-producing field varies in some proportion with the current in the armature (which latter is generally the rotor.) See §**4064**.

Classification by Neutralization and Compensation.

4069 Neutralized Commutator Motor.—A neutralized commutator motor is one in which use is made of a winding for producing a magnetizing force which at each instant and at each point in the air-gap under the pole face is practically equal and opposite to the magnetizing force due to the armature current.

4070 Compensated Commutator Motor.—A compensated commutator motor is one in which means, other than a neutralizing winding, are provided within the motor for improving the power-factor.

Classification by Energy Reception

4071 Conduction Commutator Motor.—A conduction commutator motor is one in which the working energy is supplied to only one

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(4067) Alternating-current commutator motors of this class will in general have load-speed characteristics similar to those of the direct-current shunt motor, but not all alternating-current commutator motors having such load-speed characteristics are constant-field machines.

(4068) Such a motor will in general have load-speed characteristics similar to those of the direct-current series motor.

of the members, and is conveyed to it by conduction. By "working energy" is meant the energy which is directly converted into mechanical energy, and which includes the shaft energy output plus core losses and friction.

4072 **Transformer Commutator Motor.**—A transformer commutator motor is one in which the working energy is transmitted from one member to the other by transformer action.

A motor in which the energy required by its armature (which is generally the rotor) is conveyed to it by electromagnetic induction or transformer action, may properly be referred to either as an "induction motor," or as a "transformer motor". Although it is equally applicable to a motor having a commutator, the term "induction motor" is usually applied to a motor without a commutator. The term "transformer commutator motor" is therefore recommended for use with motors of the induction, or transformer type, having commutators.

4073 **Transformer-Conduction Commutator Motor.**—A transformer-conduction commutator motor is one in which the energy required by its armature (which is generally the rotor) is conveyed to it by both conduction and electromagnetic induction.

4074 **Repulsion Commutator Motor.**—A repulsion commutator motor is a transformer commutator motor in which use is made of brushes for short-circuiting a number of coils of the commutated winding.

Miscellaneous Definitions

4085 **Saturation Factor.**—The saturation factor of a machine is the ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. Unless otherwise specified, the saturation factor of a machine refers to the no-load excitation required at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

4086 **Percentage Saturation.**—The percentage saturation of a machine at any excitation may be found from its saturation curve (generated voltage as ordinates, against excitation as abscissas), by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in per cent, is the percentage saturation, and is independent of the scales selected for excitation and voltage. This ratio as a fraction, is equal to the reciprocal of the saturation-factor at the same excitation, deducted from unity; or, if f be the saturation factor and p the percentage saturation,

$$p = 100\left(1 - \frac{1}{f}\right)$$

4088* Variation in Alternators.—The variation in alternators, or alternating-current circuits in general is the maximum angular displacement, expressed in electrical degrees (see §3222) of corresponding ordinates of the voltage wave and of a wave of absolutely constant frequency equal to the average frequency of the alternator or circuit in question, and may be due to the variation of the prime mover. See §§ 14010 and 14011.

4089 Per cent Resistance Drop.—The per cent resistance drop in an electric machine is the ratio of the internal resistance drop at 75° C. to the terminal voltage expressed in per cent.

Unless otherwise specified this per cent drop shall be referred to rated load and rated power factor.

The per cent resistance drop in an induction motor is expressed in terms of the internally induced electromotive force.

4090 Per cent Reactance Drop.—The per cent reactance drop in an electric machine or apparatus is the ratio of the internal reactance drop to the terminal voltage, expressed in per cent.

Unless otherwise specified this per cent drop shall be referred to rated load and rated power factor.

The per cent reactance drop in an induction motor is expressed in terms of the internally induced electromotive force.

4091 Per cent Impedance Drop.—The per cent impedance drop in an electric machine is the ratio of the internal impedance drop at 75° C. to the terminal voltage, expressed in per cent.

Unless otherwise specified this per cent drop shall be referred to rated load and rated power factor.

The per cent impedance drop in an induction motor is expressed in terms of the internally induced electromotive force.

4092 Magnetic Degree.—A magnetic degree is the 360th part of the angle subtended, at the axis of a machine, by a pair of its field poles. One *mechanical degree* is thus equal to as many magnetic degrees as there are pairs of poles in the machine.

4094 Regulation of D-C. Generators.—The regulation of a d-c. generator is usually stated by giving the numerical values of the voltage at no load and rated load, and in some cases it is advisable to state regulation at intermediate loads. The regulation of d-c. generators refers to changes in voltage corresponding to gradual changes in load, and does not relate to the comparatively large momentary fluctuations in voltage that frequently accompany instantaneous changes in load.

4095 Regulation of Constant-Potential A-C. Generators.—In constant-potential a-c. generators, the regulation is the rise in voltage (when the specified load at specified power factor is reduced to zero) expressed in per cent of normal rated-load voltage.

4096 Regulation of Constant-Current Machines.—In constant-current machines the regulation is the ratio of the maximum difference of

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(4088) If p is the number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct-connected, and pn times the variation of the prime mover if rigidly connected thereto in such a manner that the angular speed of the alternator is n times that of the prime mover.

current from the rated-load value (occurring in the range from rated-load to short-circuit, or minimum limit of operation), to the rated-load current.

4097 **Regulation of Constant-Speed Motors.**—In constant-speed direct-current motors and induction motors, the regulation is the ratio of the difference between full-load and no-load speeds to the no-load speed.

4098 **Regulation of Converters, Dynamotors, Motor-Generators and Frequency Converters.**—In converters, dynamotors, motor-generators, and frequency converters, the regulation is the change in the terminal voltage of the output side between the two specified loads. This may be expressed by giving the numerical values, or as the percentage of the terminal voltage at rated load.

OPERATION

Temperature Limits

4105 **Exceptions to General Temperature Limits Given in Chapter II.**—

(a) Railway Motors: See §§**5202** and **5101.**

(b) Automobile Propulsion Machines: See §**5205.**

(c) Railway Substation Machines: See §§**5201** and **5102.**

(d) Squirrel Cage and Amortisseur Windings. The temperature may attain any value such as will not occasion mechanical injury to the machine.

(e) Field Control Railway Motors: See §**5204.**

4106 **Collector Rings.**—The observable temperature of collector rings shall not be permitted to exceed the values set forth in §**2231** (c) for the insulations employed either in the collector rings themselves or in adjacent insulations whose life would be affected by the heat from the collector rings.

4107 **Commutators.**—The observable temperature shall in no case be permitted to exceed the values given in §**2231** (c) for the insulation employed either in the commutator or in an insulation whose life would be affected by the heat of the commutator. These temperature limits are intended only to protect the insulation of the commutator and of the adjacent parts and are not intended as a criterion of successful commutation.

4108 **Cores.**—The observable temperature of those parts of the iron core in contact with insulating materials shall in no case be permitted to exceed the values given in §§**2231** (c) for the insulation employed.

4109 **Other Parts, (Such as Brush-Holders, Brushes, Bearings, Pole-Tips, Cores, etc.)**—All parts of electrical machinery other than those whose temperature affects the temperature of the insulating material may be operated at such temperatures as shall not be injurious in any other respect.

4110 **Maximum Temperature Rise in Service.**—Whatever may be the ambient temperature when the machine is in service, the limits of the maximum observable temperature or of temperature rise specified in the rules should not be exceeded in service; for, if the maximum

temperature be exceeded, the insulation may be endangered, and if the rise be exceeded, the excess load may lead to injury, by exceeding limits other than those of temperature; such as commutation, stalling load and mechanical strength. For similar reasons, loads in excess of the rating should not be taken from a machine.

RATING

Units in Which Rating Shall be Expressed

4220 **Rating of D-C. Generators.**—The rating of direct-current generators, shall be expressed in kilowatts (kw.) available at the terminals at a specified voltage.

4221 **Rating of Alternators.**—The rating of alternators shall be expressed in kilovolt-amperes (kv-a.) available at the output terminals, at a specified voltage and power factor.

4222* **Rating of Motors.**—It is strongly recommended that the rating of motors shall be expressed in kilowatts (kw.) available at the shaft. (An exception to this rule is made in the case of railway motors, which, for some purposes, are also rated by their *input*. See §5203.

4223 **Rating of Auxiliary Machinery.**—Auxiliary machinery, such as regulators, balancer sets, synchronous-condensers, etc., shall have their ratings appropriately expressed. It is also essential to specify the voltage (and frequency, if a-c.), of the circuits on which the machinery may appropriately be used.

Limitations other than Temperature Rise

4250* **Mechanical Limitations.**—*(*a*) *General*: All types of rotating machines shall be so constructed that they will safely withstand an over-speed of 25 per cent, except in the case of steam turbines, which, when equipped with emergency governors, shall be constructed to withstand 20 per cent over-speed.

(*b*) *Generators*: Water-wheel generators shall be constructed for the maximum runaway speed which can be attained by the combined unit.

(*c*) *Motors*: Motors for continuous service shall, except when otherwise specified, be required to develop running torque at least 175 per cent of that corresponding to the running torque at their rated load, without stalling. Obviously, duty-cycle machines must carry their peak loads without stalling.

(4222) Since the input of machinery of this class is measured in electrical units and since the output has a definite relation to the input, it is logical and desirable to measure the delivered power in the same units as are employed for the received power. Therefore, the output of motors should be expressed in kilowatts instead of in horse power. However, on account of the hitherto prevailing practise of expressing mechanical output in horse power, it is recommended that for machinery of this class the rating should, for the present, be expressed both in kilowatts and in horse power; as follows:

Kw.————Approx. equiv. h.p.————

For the purposes of these rules the horsepower shall be taken as 746.0 watts.

In order to lay stress upon the preferred future basis, it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the rating in horse power.

One kilowatt is equal to 102 kilogrammeters per second.

(4250-a) In the case of series motors, it is impracticable to specify percentage values for the guaranteed overspeed, on account of the varying service conditions.

4251 **Commutation Limitations.**—(*a*) *Continuously Rated Machines*: Continuously rated machines shall be required to commutate successfully momentary loads of 150 per cent of the amperes corresponding to the continuous rating, keeping the rheostat set for rated load excitation. Successful commutation is such that neither brushes nor commutator are injured by the test. See §§**2220** and **5203**.

(*b*) *Machines for Duty-Cycle Operation*: Machines for duty-cycle operation with widely fluctuating loads, shall commutate successfully under their specified operating conditions. See §§**2222** and **2223**.

4252 **Limitations of Stability.**—Continuously rated machines shall be required to carry momentary loads of 150 per cent of the amperes corresponding to the continuous rating, keeping the rheostat set for rated load excitation.

In the case of direct-connected generators, this clause is not to be interpreted as requiring the prime mover to drive the generator at this overload.

TESTS

Ambient Temperature

4300 **Measurement of the Ambient Temperature During Tests of Machines.**—(See §**2300**) (a) *Machines Cooled by Forced Draught*: In the testing of rotating machines, cooled by forced draught, a conventional weighted mean shall be employed, a weight of four being given to the temperature of the circulating air supplied through ducts and a weight of one to the surrounding room air. See §**2300** Note.

(*b*) *Machines Below Floor Line*: Where machines are partly below the floor line in pits, the temperature of the rotor shall be referred to a weighted mean of the pit and room temperatures, the weight of each being based on the relative proportions of the rotor in and above the pit. Parts of the stator constantly in the pit shall be referred to the ambient temperature in the pit.

Machine Temperatures

4316 **Machines with Small Ventilating Apertures.**—Machines having ventilating openings smaller than 0.02 sq. in. (0.13 sq. cm.) in area, when intended to be operated in locations or under conditions where the openings are liable to become clogged, should be considered as totally enclosed machines and tested as such with openings closed, and in all cases the rating on this basis should be indicated on the rating plate.

4319 **Exception to Temperature Limits Used in Method 1.**—In the case of enclosed motors and generators, the limits of the observable temperature rise shall be 5°C. higher than allowed by the general rule. This rule does not apply to those types of machines defined in §§ **4043, 4045** and **4046.**

4320 **Exception to Temperature Limits Used in Method 2.**—In the case of enclosed motors and generators, the limits of the observable temperature rise shall be 5°C. higher than allowed by the general rule. This rule does not apply to those types of machines defined in §§. **4043, 4045** and **4046.**

4321 Method of Temperature Measurement Used in Determining Temperature of Stators of Machines.—Method 3 should be applied to all stators of machines with cores having a width of 50 cm. (20 in.) or over. It should also be applied to all machines of 5000 volts or more, if rated over 500 kv-a., regardless of core width.

Efficiency

4334* Classification of Losses.—Losses are classified as shown in Table 401.

4335 Losses to be Considered in Machines.—Conventional efficiencies shall be based upon the losses listed in Table 402, and these losses shall be measured as specified in §§**4336-4342** inclusive.

TABLE 401

Classification of Losses in Machinery

Accurately Measurable	Approximately Measurable or Determinable	Indeterminable
No-load core losses. including eddy-current losses in conductors at no-load	Brush Friction loss	Iron loss due to flux distortion
Load I^2R losses in windings No-load I^2R losses in windings	Brush-contact loss	Eddy-current losses in conductors due to transverse fluxes occasioned by the load currents
	Losses due to windage and to bearing friction	Eddy-current losses in conductors due to tooth saturation resulting from distortion of the main flux
		Tooth-frequency losses due to flux distortion under load
	Dielectric losses	Short-circuit loss of commutation

(4334) The losses in constant-potential machinery, either of the stationary type, or of the constant-speed rotary type, are of two classes; namely, those which remain substantially constant at all loads, and those which vary with the load. The former include iron losses, windage and friction, also I^2R losses in any shunt windings. The latter include I^2R

4336 I^2R **Loss.**—(*a*) *General*: The I^2R loss shall be based upon the current and the measured resistance.

(*b*) *Polyphase Induction-Motor Rotor*: The I^2R loss in the rotors of polyphase induction motors should be determined from the slip, whenever the latter is accurately determinable, using the following equation:

$$\text{Rotor } I^2 R \text{ loss} = \frac{\text{output} \times \text{slip}}{1 - \text{slip}}$$

TABLE 402

Losses in Rotating Electric Machines
(References are to Sections)

	I^2R Loss Windings	Friction and Windage	Brush Friction	Core Loss	Brush Contact I^2R Loss	Stray Load Losses
D-C commutating machines (Note 1)	4336(a)	4337(a)	4338	4339	4341 5341	Note 5
A-C commutating machines (Note 1)	4336(a)	4337(a)	4338	4339	4341	Note 5 5339
Railway motors	4336(a)	5337 5338	5338 5339	5339	4341	Note 5 5339
Synchronous motors and generators (Note 4)	4336(a)	4337(a)	4338 Note 3	5339 4339	4341 Note 3	4342(b)
Synchronous converters	4336(c)	4337(a)	4338	4339(a) 4339(b)		Note 5
Induction machines	4336(b)	4337(a)	4338	4339(a) 4339(c)	4341 Note 2	4342(b)

Notes:—(1) Except railway motors.

(2) When there are collector rings.

(3) Brush friction and brush contact losses are negligible except in the case of revolving armature machines.

(4) For the booster type of synchronous converter, where the booster forms an integral part of the unit, its losses shall be included in the total converter losses in estimating the efficiency.

(5) These losses, while usually of low magnitude, are erratic, and the Institute is not at this time prepared to make recommendations for approximating them.

losses in series windings. The constant losses may be determined by measuring the power required to operate the machine at no load, deducting any series I^2R losses. The variable loss at any load may be computed from the measured resistance of the series windings and the given load current.

(4335) This simple method of determining the losses and hence the efficiency is only approximate, since the losses which are assumed to be constant do actually vary to some extent with the load, and also because the actual loss in the copper windings is sometimes appreciably greater than the calculated I^2R loss. The difference between the approximate losses, as above determined, and the actual losses, is termed "stray load losses." These latter are due to distortions in electric or magnetic fluxes from their no-load distributions or values, brought about by the load current. They are usually only approximately measurable, or may be indeterminable, but certain of them reach values in various kinds of machinery, which require that they should be taken into account.

Dielectric losses are usually negligible.

The stray load losses include the items in the column of Table 401 headed "Indeterminable" but do not include the increased core losses due to increased excitation for compensating internal drop under load.

In large slip-ring motors, in which the slip cannot be directly measured by loading, the rotor I^2R loss shall be determined by direct resistance measurement; the rotor full-load current to be calculated by the following equation:

$$\text{Current per ring} = \frac{\text{watts output}}{\text{rotor voltage at stand-still} \times \sqrt{3} \times K}$$

This equation applies to three-phase rotors. For rotors wound for two phase, use 2 instead of the $\sqrt{3}$. K may be taken as 0.95 for motors of 150 kw. or larger. The factor K usually decreases as the size of motor is reduced, but no specific value can be stated for smaller sizes.

(*c*) *Synchronous Converter*: The I^2R losses in the armature winding shall be derived from those corresponding to its use as a direct-current generator, by using suitable factors.

4337 Bearing Friction and Windage.—(*a*) *General*: Drive the machine from an independent motor, the output of which shall be suitably determined. The machine under test shall have its brushes removed and shall not be excited. This output represents the bearing friction and windage of the machine under test.

(*b*) *Induction Motors*: The bearing friction and windage of induction motors may be measured by running motors free at the lowest voltage at which they will rotate continuously at approximately rated speed; the watts input, minus I^2R loss, under these conditions being taken as the friction and windage.

(*c*) *Engine-Type Generators*: In the case of engine-type generators, (See §**4027**) the windage and bearing friction loss is ordinarily very small, amounting to a fraction of one per cent of the output. This loss shall be neglected owing to its small value and the difficulty of measuring it.

(*d*) *D. C. Railway Motors*: See §**5337.**

4338 Brush Friction of Commutator and Collector Rings.—(*a*) *General*: Drive the machine from an independent motor, the output of which shall be suitably determined. The brushes shall be in contact with the commutator or collector rings, but the machine shall not be excited. The difference between the output obtained in the test in §**4337** and this output shall be taken as the brush friction. The surfaces of the commutator and brushes should be smooth and glazed from running when this test is made.

(*b*) *D. C. Railway Motors*: See §**5338.**

4339 Core Losses.—(*a*) *General*: Drive the machine from an independent motor, the output of which shall be suitably determined. The brushes shall be in contact, and the machine shall be excited, so as to produce at the terminals a voltage corresponding to the calculated internal voltage for the load under consideration. The difference between the output obtained by this test and that obtained by test under §**4338** (*a*) shall be taken as the core loss.

(*b*) *Synchronous Machines*: The internal voltage of synchronous machines shall be determined by correcting the terminal voltage for the resistance drop only.

(c) *Induction Motors*: The core loss of an induction motor may be determined by measuring the watts input to the motor when running free at rated voltage and frequency and subtracting therefrom the no-load copper loss, bearing friction and windage.

(d) *D. C. Railway Motors*: See §**5339.**

4341* **Brush-Contact I^2R Loss.**—(a) *General*: One volt drop per brush shall be considered as the Institute standard drop corresponding to the I^2R brush-contact loss, for carbon and graphite brushes with pigtails attached. One and one-half volts per brush shall be allowed where pigtails are not attached. Metal-graphite brushes shall be considered as special.

(b) *Automobile Motors*: See §**5341.**

4342* **Stray Load-Losses.**—(a) *Synchronous Machines*: These include iron losses, and eddy-current losses in the copper, due to fluxes varying with load and also to saturation.

Stray load-losses shall be determined by operating the machine on short circuit and at rated-load current. This, after deducting the windage and friction and I^2R loss, gives the stray load-loss for polyphase generators and motors. These losses in single-phase machines are large; but the Institute is not yet prepared to specify a method for measuring them.

(b) *Induction Machines*: These include eddy-current losses in the stator copper, and other eddy-current losses due to fluxes varying with the load. In windings consisting of relatively small conductors, these eddy-current losses are usually negligible.

With rotor removed, measure the power input to the stator with different values of current at the rated frequency. The curve plotted with these values gives the combined I^2R and stray load-losses due to eddy-currents in the stator copper. Deduct the I^2R loss determined from the resistance, and the difference will represent the stray load-losses corresponding to the various currents. While this method is not accurate for some types of motors it usually represents a sufficiently good approximation.

(4341) The brush-contact I^2R loss depends largely upon the material of which the brush is composed.

As indicating the range of variation the following table will be of interest:

TABLE 403

Brush-Contact Drop

Grade of brush	Volts drop across one brush-contact (Average of positive and negative brushes)
Hard carbon	1.1
Soft carbon	0.9
Graphite	0.5 to 0.8
Metal-graphite types	0.15 to 0.5 (The former for largest proportion of metal)

(4342) Values of the indeterminate losses may also be obtained by brake or other direct test and used in estimating actual efficiencies of similar machines by the separate-loss method.

4343 Miscellaneous Losses.—(*a*) *Field-Rheostat Losses*: Field-Rheostat losses shall be included in the generator losses where there is a field rheostat in series with the field magnets of the generator, even when the machine is separately excited.

(*b*) *Ventilating Blower*: When a blower is supplied as part of a machine set, the power required to drive it shall be charged against the complete unit, but not against the machine alone.

(*c*) *Other Auxiliary Apparatus*: Auxiliary apparatus, such as a separate exciter for a generator or motor, shall have its losses charged against the plant of which the generator and exciter are a part, and not against the generator. An exception should be noted in the case of turbo-generator sets with direct-connected exciters, in which case the losses in the exciter shall be charged against the generator. The actual energy of excitation and the field-rheostat losses, if any shall be charged against the generator. See §**4343** (*a*).

Wave Shape

4351 Deviation Factor of a Wave.—The deviation factor of the open circuit terminal voltage wave of synchronous machines shall not exceed ten per cent unless otherwise specified. See §**3274.**

4352* Telephone Interference Factor of a Wave. (For trial only.) (See §**3278.**)—(*a*) *Conditions of Test.* The weighting of the sine wave components of different frequencies shall be as given in Fig. 4—1.

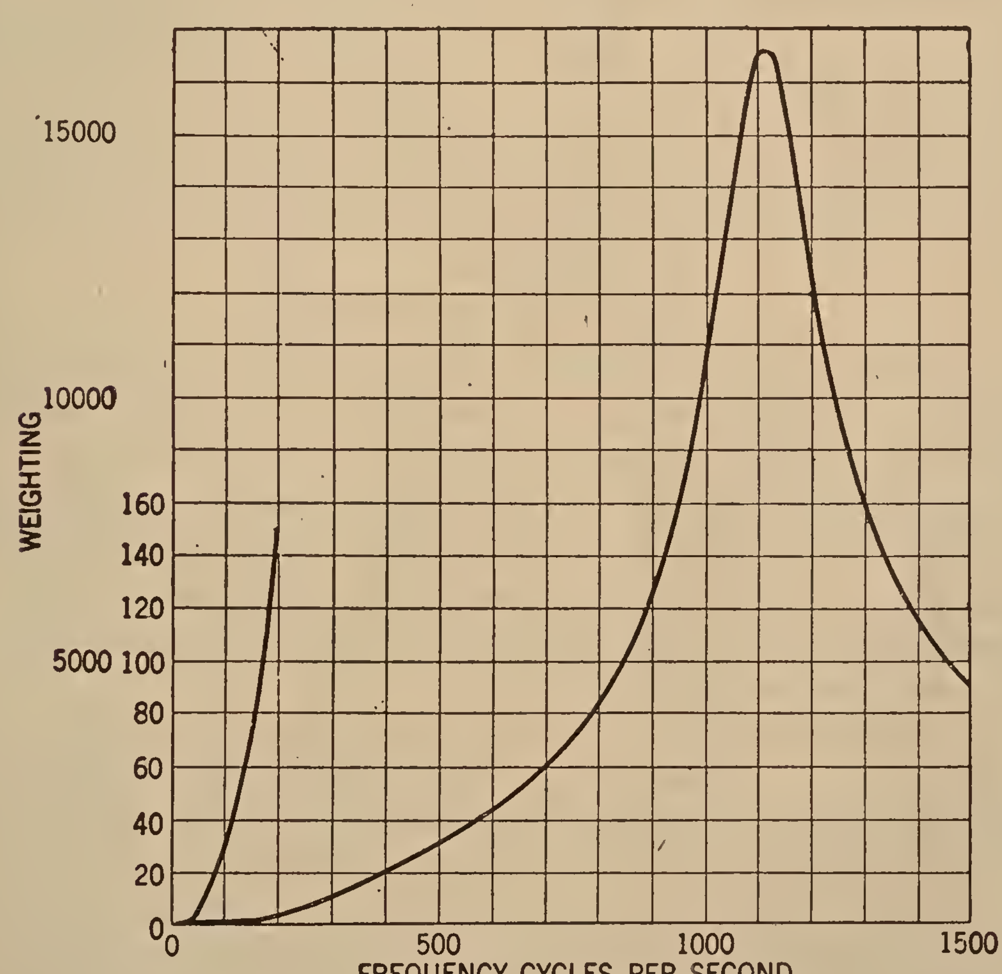
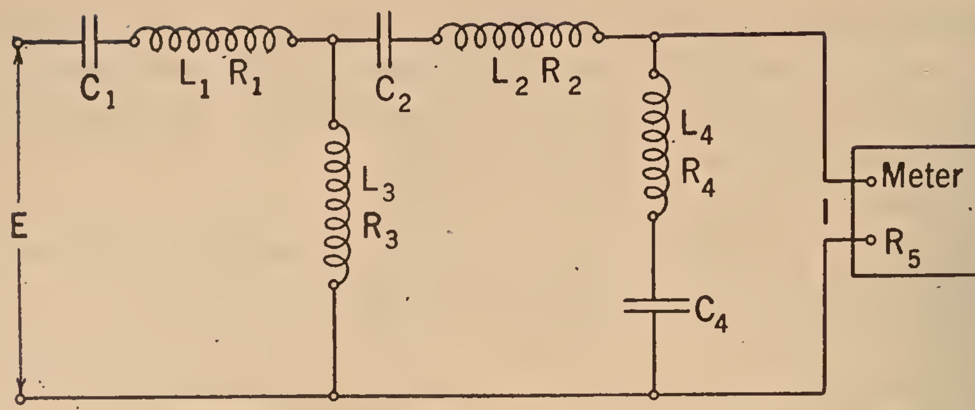


Fig. 4–1

The telephone interference factor of a voltage wave, corresponding to this weighting, may be measured by the use of the network shown in Fig. 4—2.



Network Constants

$C_1 = 0.9$ mf.		$L_1 = 0.023$ henry		$R_1 = 5$ ohms	$\pm 2\%$
$C_2 = 0.9$ "	$\pm 0.5\%$	$L_2 = 0.0205$ "	$\pm 0.5\%$	$R_2 = 12$ "	$\pm 2\%$
		$L_3 = 0.068$ "		$R_3 = 73$ "	$\pm 1\%$
$C_4 = 7.5$ "		$L_4 = 0.019$ "		$R_4 = 22.5$ "	$\pm 2\%$
				$R_5 = 43$ "	$\pm 1\%$

FIG. 4–2

With this network the telephone interference factor of a voltage wave is the ratio of the current I in micro-amperes in the meter branch of the network to the voltage E applied to the external terminals of the network. The measurement may be made on the low tension side of a potential transformer. A sensitive vacuum thermo-couple provided with a shunt, and a direct-current mil-ammeter have been found convenient for measuring the current.

(*b*) The appropriate limiting value of the telephone interference factor of a wave (See §**3278**), either for machines or for circuits, has not yet been determined, and cannot now be specified. The whole matter of interference, including reasonable requirements for both power and communication systems, is under discussion, in consultation with power, telephone, and other interests concerned.

Tests of Dielectric Strength

4358 Frequency of Test Voltage.—In d-c. machines, and in general commercial application of a-c. machines, the testing frequency of 60 cycles per second is recommended.

4361* Exceptions to Standard Test Voltage Given in Section 2356.

(*a*) *Field Windings of Alternating Current Generators*: Field windings of alternating current generators shall be tested with 10 times the exciter voltage, but in no case with less than 1500 volts nor more than 3500 volts.

*(b) *Field Windings of Synchronous Machines*: Field windings of synchronous machines including motors and converters which are to be started with alternating current are to be tested as follows:

When machines are to be started with field short circuited, the field windings shall be tested as specified in §**4361** (a).

When machines are to be started with fields open circuited and

(4361-*b*) Series field windings should be regarded as part of the armature circuit and tested as such.

sectionalized while starting, the field windings shall be tested with 5000 volts.

When machines are to be started with fields open circuited and connected all in series while starting, the windings shall be tested with 5000 volts for less than 275 volts excitation and 8000 volts for excitation of 275 volts to 275 volts.

*(c) *Phase-Wound Rotors of Induction Motor*: The secondary windings of wound rotors of induction motors shall be tested with twice their normal induced voltage, plus 1000 volts. When induction motors with phase-wound rotors are to be reversed, while running at approximately normal speed, by reversing the primary connections, the test shall be four times the normal induced voltage plus 1000 volts.

(d) *Small Motors and Generators*: Small machines taking not over 660 watts or having an output not exceeding ½ h. p. (373 watts), such as fractional horse power motors, and intended solely for operation on supply circuits not exceeding 275 volts, shall be tested with 900 volts.

(e) *Alternating Current Machines Connected to Permanently Grounded Single-Phase Systems*: Alternating current machines connected to permanently grounded single-phase systems, for use on permanently grounded circuits operating at more than 300 volts shall be tested with 2.73 times the voltage of the circuit to ground, plus 1000 volts. This does not refer to three-phase machines with grounded star neutral.

*(f) *Machines for Use on Circuits of 25 Volts or Lower*: Machines for use on circuits of 25 volts or lower, such as bell ringing apparatus, electric machines used in automobiles, machines used on low voltage battery circuits, etc., shall be tested with 500 volts.

Regulation

4390 Conditions for Tests of Regulation (See §2390).—(*a*) *Power Factor*: In alternating current generators the power factor of the load to which the regulation refers should be specified. Unless otherwise specified, it shall be understood as referring to non-inductive load, that is, to a load in which the current is in phase with the e. m. f. at the terminals of the machine.

(*b*) *Excitation*: In communtating machines, rectifying machines and synchronous machines, the regulation shall be determined under such conditions as to maintain the field adjustment constant at a value which gives rated-load voltage at rated-load current. These conditions are as follows:

In the case of separately excited fields: constant excitation.

In the case of shunt machines: constant resistance in the shunt-field circuit.

In the case of series or compound machines: constant resistance shunting the series field windings.

4394* Tests and Computation of Regulation of A-C. Generators.—(a) *Methods Available:* The regulation of alternating-current gen-

(4361-c) By normal induced voltage is here meant the voltage between slip rings on open circuit at standstill with normal voltage impressed on the primary.

(4361-*f*) The present National Electrical Code limit for a single outlet is 660 watts.

erators may be determined by any one of the three following methods, which are given in the order of preference:

(b) *Method I. By Loading:* The regulation can be measured directly, by loading the generator at the specified output and power factor, then reducing the load to zero, and measuring the terminal voltage, with speed and excitation adjusted to the same values as before the change. This method is not generally applicable for shop tests, particularly on large generators and it becomes necessary to determine the regulation from such other tests as can be readily made.

*(c) *Method II. From Test Curves:* This method consists in computing the regulation from experimental data of the open-circuit saturation curves and the zero-power-factor saturation curve. The latter curve, or one approximating very closely to it, can be obtained by over-exciting the generator while carrying

(4394-c) Method II for deducing the load saturation curve, at any assigned power factor, from no-load and zero power-factor saturation curves obtained by test, must be regarded as empirical. Its value depends upon the fact that experience has demonstrated the reasonable correctness of the results obtained by it.

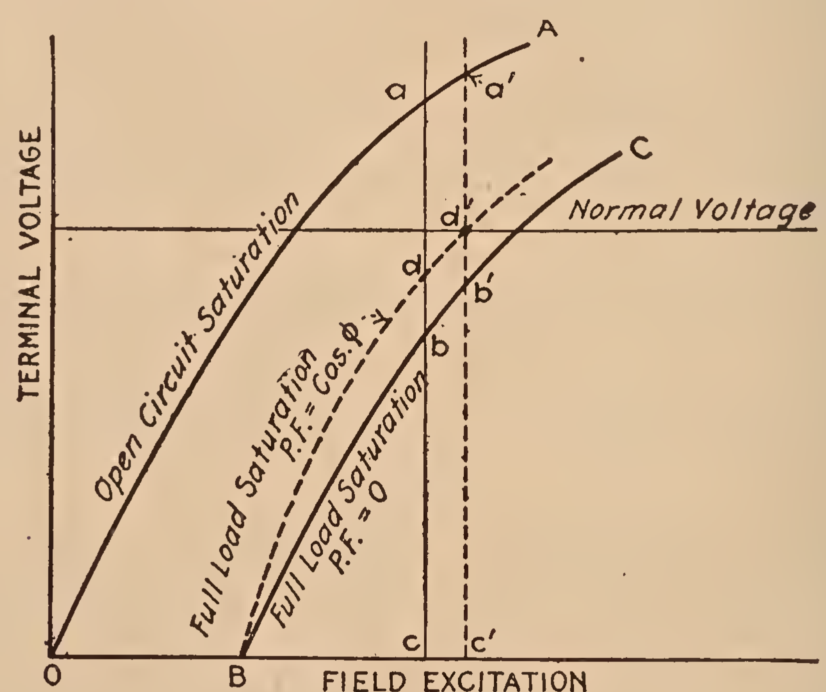


FIG- 4-3

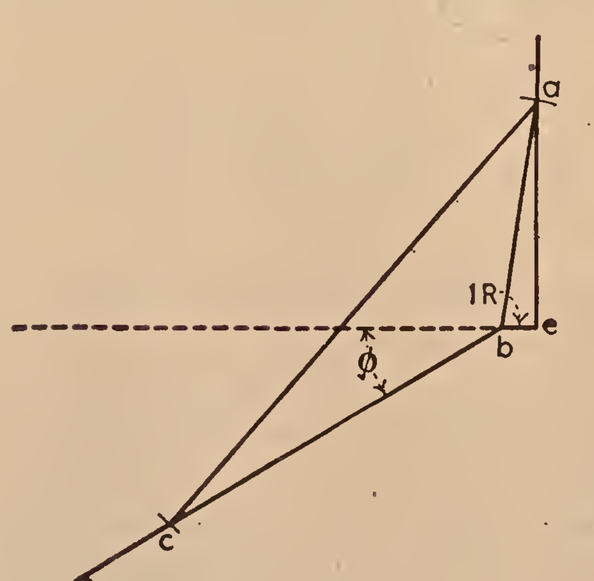


FIG. 4-4

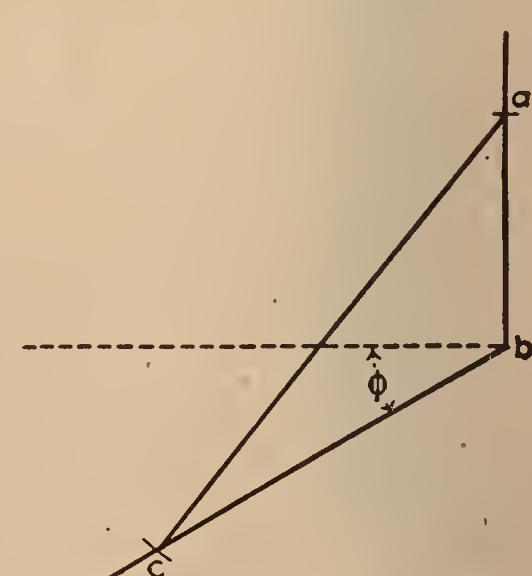


FIG. 4-5

a load of idle-running under-excited synchronous motors. The power factor under these conditions is very low and the load saturation curve approximates very closely the zero power-factor saturation curve. From this curve and the open circuit curve, points for the load saturation curve for any specified power factor can be obtained by means of vector diagrams.

*(d) *Method III. From Estimated Zero Power Factor Curve* Where it is not possible to obtain by test a zero power factor curve as in Method II this curve can be estimated closely from open-

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To apply method II, it is necessary to obtain from test the open circuit saturation curve Fig. 4-3, and the load saturation curve *B C* at zero power factor and rated-load current. At any given excitation *O c*, the voltage that would be induced on open circuit is *c a*, the terminal voltage at zero power factor is *c b* and the apparent internal drop is *a b*. The terminål voltage *c d* at any other power factor can then be found by drawing an e.m.f. diagram as in Fig. 4-4. where ϕ is an angle such that cos ϕ is the power factor of the load, *b e* the resistance drop (*I R*) in the stator winding, *b a* the total internal drop and *a c* the total induced voltage; *b a* and *a c* being laid off to correspond with the values obtained from Fig.4-3.

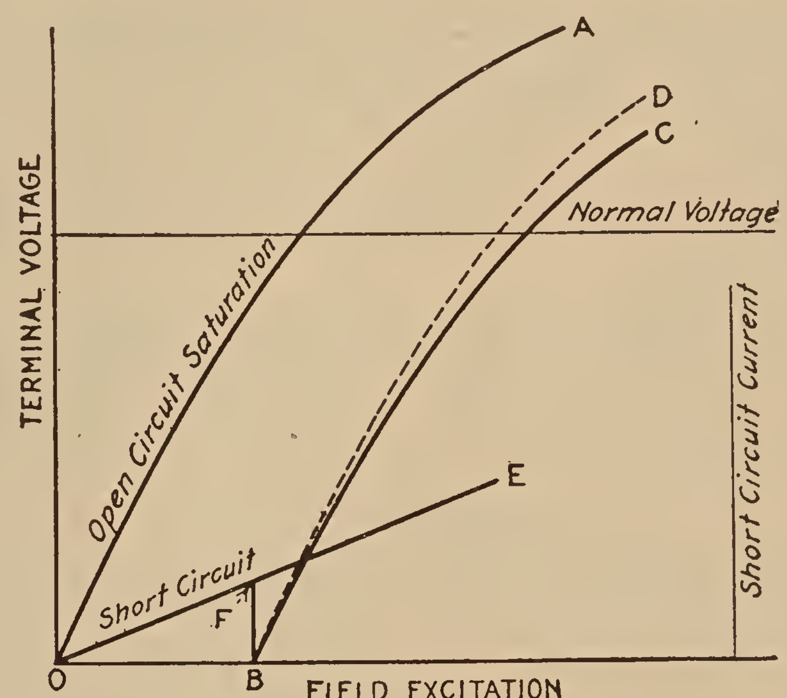

FIG. 4-6

The terminal voltage at power factor cos ϕ is then *c b* Fig. 4-4, which when laid off in Fig. 4 3 gives point *d*. By finding a number of such points, the curve *B d d'* for power factor cos ϕ is obtained and the regulation at this power factor (expressed in per cent) is $\dfrac{100 \times a'\,d'}{c'\,d'}$ since *a' d'* is the rise in voltage when the load at power factor cos ϕ is thrown off at normal voltage *c' d'*.

Generally, the ohmic drop can be neglected as it has little influence on the regulation, except in very low-speed machines where the armature drop is relatively high or in some cases where regulation at unity power factor is being estimated. For low power factors its effect is negligible in practically all cases. If resistance is neglected, the simpler diagram Fig. 4-5, may be used.

(4394-d) Method III is the same as Method II except that the zero power factor curve must be estimated. This may be done as follows. In Fig. 4-6, *OA* is the open-circuit saturation curve and *O E* the short-circuit line as obtained from test. The zero power-factor curve corresponding to any current *B F* will start from point *B*, and for machines designed with low saturation and low reactance, will follow parallel to *O A* as shown by the dotted curve *B D*, which is *O A* shifted horizontally parallel to itself by the distance *O B*. In high speed machines, or in others having low reactance, and a low degree of saturation in the magnetic

circuit and short-circuit curves, by reference to tests at zero power factor on other machines of similar magnetic circuit. Having obtained the estimated zero power-factor curve, the load saturation for any other power factor is obtained as in Method II, §**4394** (c).

4395 **Compound Wound D-C. Generator.**—In determining the regulation of a compound-wound d-c generator, two tests shall be made, one bringing the load down and the other bringing the load up, between no-load and rated load. These may differ somewhat, owing to residual magnetism. The mean of the two results shall be used.

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circuit, the zero power factor curve will be quite close to *B D* particularly in those parts that are used for determining the regulation. This is the case with many turbo-generators and high-speed water-wheel generators.

In many cases, however, the zero power-factor curve will deviate from *B D*, as shown by *B C* and the deviation will be most pronounced in machines of high reactance, high saturation and large magnetic leakage. The position of curve *B C* with relation to *B D* can be approximated with sufficient exactness by investigating the corresponding relation as obtained by test at zero power factor on machines of similar characteristics and magnetic circuit. Curve *B C* can also be calculated by methods based on the results of tests at zero power factor. After curve *B C* has been obtained, the load saturation curve and regulation for any other power factor can be derived as in Method II, §**4394** (c).

CHAPTER V.

STANDARDS FOR ELECTRIC RAILWAYS AND FOR AUTOMOBILE PROPULSION MACHINES

The A. I. E. E. Standards for Electric Railways and for Automobile Propulsion Machines are the General Standards shown in Chapters II and III, and the Standards in other Chapters which are applicable to the devices involved together with the modifications and extensions given in this Chapter.

DEFINITIONS

General

5000 **Contact Conductors.**—A contact conductor is that part of the distribution system other than the traffic rails, which is in immediate electrical contact with the circuits of the cars or locomotives.

Contact Rails

5003* **Contact Rail.**—(a) *General:* A contact rail is a rigid contact conductor.

*(b) *Overhead Contact Rail:* An overhead contact rail is a contact rail which is above the elevation of the maximum equipment line.

(c) *Third Rail:* A third rail is a contact conductor placed at either side of the track, the contact surface of which is a few inches above the level of the top of the track rails.

(d) *Center Contact Rail:* A center contact rail is a contact conductor placed between the track rails, having its contact surface above the ground level.

(e) *Underground Contact Rail:* An underground contact rail is a contact conductor placed beneath the ground level.

(f) *Gage of Third Rail:* The gage of a third rail is the distance, measured parallel to the plane of running rails, between the gage line of the nearer track rail and the inside gage line of the contact surface of the third rail.

(g) *Elevation of Third Rail:* The elevation of a third rail is the elevation of the contact-surface of the third rail, with respect to the plane of the tops of running rails.

(h) *Third Rail Protection:* A third rail protection is a guard for the purpose of preventing accidental contact with the third rail.

Trolley Wires

5004 **Trolley Wire.**—A trolley wire is a flexible contact conductor, customarily supported above the cars.

(5003b) The maximum equipment line is the contour which embraces cross-sections of all rolling stock under all normal operating conditions.

5005 **Messenger Wire or Cable.**—A messenger wire or cable is a wire or cable running along with and supporting other wires, cables or contact conductors.

A primary messenger is directly attached to the supporting system. A secondary messenger is intermediate between a primary messenger and the wires, cables or contact conductors.

5006 **Classes of Construction.**—(a) *General:* Overhead trolley constructions are classed as *Direct Suspension* and *Messenger or Catenary Suspension.*

(b) *Direct Suspension:* A direct suspension is the form of overhead trolley construction in which the trolley wires are attached, by insulating devices, directly to the main supporting system.

(c) *Messenger or Catenary Suspension:* A messenger or catenary suspension is the form of overhead trolley construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables, which in turn may be carried either in *Simple Catenary*, *i.e.*, by primary messengers, or in *Compound Catenary*, *i.e.*, by secondary messengers.

5007 **Supporting Systems.**—(a) *General:* Supporting systems for trolley wires shall be classed as follows:

(b) *Simple Cross-Span Systems:* Simple cross-span systems are those having at each support a single flexible span across the track or tracks.

(c) *Messenger Cross-Span Systems:* Messenger cross-span systems are those having at each support two or more flexible spans across the track or tracks, the upper span carrying part or all of the vertical load of the lower span.

(d) *Bracket Systems:* Bracket systems are those having at each support an arm or similar rigid member, supported at only one side of the track or tracks.

(e) *Bridge Systems:* Bridge systems are those having at each support a rigid member, supported at both sides of the track-or tracks.

5030* **Transmission System.**—When the current generated for an electric railway is changed in kind or voltage, between the generator and the cars or locomotives, that portion of the conductor system carrying current of a kind or voltage substantially different from that received by the cars or locomotives, constitutes the *transmission system.*

5031* **Distribution System.**—That portion of the conductor system of an electric railway which carries current of the kind and voltage received by the cars or locomotives, constitutes the *distribution system.*

(5030 and 5031) These definitions are identical in sense, although not in words, with those of the Interstate Commerce Commission, as given in their Classification of Accounts for Electric Railways.

5032 **Substation.**—A substation is a group of apparatus or machinery which receives current from a transmission system, changes its kind or voltage, and delivers it to a distribution system.

OPERATION

Temperature Limits

5101* **Railway Motors in Continuous Service.**—The following maximum observable temperatures are permissible in the windings of railway motors, when in continuous service.

TABLE 501

Temperatures of Railway Motors in Continuous Service.

Class of Material See §**1004**	Temperature	
	By Thermometer See §**1002**	By Resistance See §**1002**
A	85°C	110°C
B	100°C	130°C

5120 **Railway Substation Machines and Transformers.**—Under conditions specified in §**5201**, the windings of railway substation machines and transformers carrying traction loads may have observable temperature rises 5°C in excess of the limiting observable temperature rises specified in Table 200.

5130* **Automobile Propulsion Machines.**—On stand test, the *observable* temperature rises shall not exceed the limits specified in §**5205.**

RATING

Ratings of Railway Substation Machinery and Transformers.

5201* **Nominal Rating of Railway Substation Machines and Transformers.**—The nominal rating of a substation machine or transformer carrying traction loads shall be the kv-a. output at a stated power factor input, which, having produced a constant temperature in the machine or transformer may be increased 50 per cent for two hours, without producing temperature rises exceeding by more than 5°C. the limiting values given in Table 200. These

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(5101) Under extreme ambient temperatures it is permissible to operate, for short infrequent periods, at 15°C. higher temperature than specified in this rule.

(5101 and 5130) Owing to space limitations and the cost of carrying dead weight on vehicles, it is considered good practise to operate propulsion machinery at higher temperatures than would be advisable in stationary machines. (See Table 501).

machines or transformers should be capable of carrying a load of twice their nominal rating for a period of one minute, without disqualifying them for continuous service. The name plate should be marked "nominal rating."

Ratings of Railway Motors

5202* **Nominal Rating of Railway Motors.**—The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90°C. at the commutator, and 75°C. at any other normally accessible part after one hour's continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature as measured by resistance, shall not exceed 100°C. The statement of the nominal rating shall include the corresponding voltage and armature speed.

5203* **Continuous Ratings of Railway Motors.**—The continuous ratings of a railway motor shall be the *inputs* in amperes at which it may be operated continuously at ½, ¾ and full voltage respectively, without exceeding the observable temperature rises specified in Table 502, when operated on stand test with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation, it will be necessary in each case to define the system of ventilation which is used. In case motors are cooled by external blowers, the flow of air on which the rating is based shall be given.

TABLE 502

Stand-Test Temperature Rises of Railway Motors

Class of Material See §1004	Temperature Rises of windings	
	By Thermometer See §1002	By Resistance See §1002
A	65°C.	85°C.
B	80°C.	105°C.

(5201 and 5202) In the absence of any specification as to the kind of rating the "nominal" rating shall be understood.

(5203) The temperature rise in service may be very different from that on stand-test. See §5502 for the relation between stand-test and service temperatures as affected by ventilation

5204 **Field-Control Railway Motors.**—The nominal and continuous ratings of field-control motors shall relate to their performance with the operating field which gives the maximum motor rating. Each section of the field windings shall be adequate to perform the service required of it, without exceeding the specified temperature rises.

Ratings of Automobile Propulsion Machines

5205 **Automobile Propulsion Machines:** The rating of automobile motors and generators shall be based upon temperature rise, on a stand test and with motor covers arranged as in service, fifteen degrees by thermometer or twenty-five degrees by resistance, above those of Table 200.

Ratings of Electric Locomotives

5210 **Rating.**—Locomotives shall be rated in terms of the weight on drivers, nominal one-hour tractive effort, continuous tractive effort and corresponding speeds.

5211 **Weight on Drivers.**—The weight on drivers, expressed in pounds, shall be the sum of the weights carried by the drivers and of the drivers themselves.

5212 **Nominal Tractive Effort.**—The nominal tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers when the motors are operating at their nominal (one-hour) rating.

5213 **Continuous Tractive Effort.**—The continuous tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers when the motors are operating at their full-voltage continuous rating, as indicated in §**5203**.

In the case of locomotives operating on intermittent service, the continuous tractive effort may be given for ½ or ¾ voltage, but in such cases the voltage shall be clearly specified.

5214 **Speed.**—The rated speed, expressed in miles per hour, shall be that at which the continuous tractive effort is exerted.

TESTS

Efficiency

Losses in D-C. Railway Motors

5337 **Losses in Gearing and Axle Bearings.**—The losses in gearing and axle bearings for single-reduction single-geared motors, varies with the type, mechanical finish, age and lubrication. The following values, based upon accumulated tests, shall be used in the comparison of single-reduction single-geared motors §**5339**.

TABLE 503

Losses in Axle Bearings and Single-Reduction Gearing of Railway Motors

Per cent of input at nominal rating	Losses as per cent of input
200	3.5
150	3.0
125	2.7
100	2.5
75	2.5
60	2.7
50	3.2
40	4.4
30	6.7
25	8.5

NOTE:—Further investigation may indicate the desirability of giving separate values of the losses for full and tapped fields, or low- and high-speed motors.

5338. Brush Friction, Armature Bearing Friction and Windage.—The brush friction, armature-bearing friction and windage, shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. Drive the machine idle as a series motor on low voltage. The product of armature counter-electromotive-force and amperes at any speed shall be the sum of the above losses at that speed. See **§5339.**

5339* No-Load Core Loss, Brush Friction, Armature-Bearing Friction and Windage.—The no-load core loss, brush friction, armature-bearing friction and windage shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for any given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above-mentioned, is equal to the product of the counter-electromotive force and the armature current.

The no-load core loss is obtained by deducting from the total

(5339) In comparing projected railway motors, and in case it is not possible or desirable to make tests to determine mechanical losses, the following values of these losses, determined from the averages of many tests over a wide range of sizes of single-reduction single-geared motors, will be found useful, as approximations. They include axle-bearing, gear, armature-bearing, brush-friction, windage, and stray-load losses.

losses thus obtained the power required to drive the motor at corresponding speeds as determined under §5338.

The core loss under load shall be assumed to have the values given in Table 504.

TABLE 504

Core Loss in D-C. Railway Motors at Various Loads

Per cent of input at nominal rating	Loss as per cent of no-load core loss
200	165
150	145
100	130
75	125
50	123
25 and under	122

NOTE:—With motors designed for field control the core losses shall be assumed as the same for both full and permanent field. It shall be the mean between the no-load losses at full and permanent field, increased by the percentages given in the above Table.

5341 Automobile Motors: When automobile motors are of low voltage, the great influence of brush-contact losses on the efficiency requires that these losses be determined experimentally for the type of brush used.

CHARACTERISTIC CURVES OF RAILWAY MOTORS

5401 General.—The Characteristic Curves of railway motors shall be plotted with the current as abscissas and the tractive effort, speed and efficiency as ordinates. In the case of a-c. motors, the power factor shall also be plotted as ordinates.

5402 Voltage.—Characteristic curves of direct current motors shall be based upon full voltage, which shall be taken as 600 volts, or a multiple thereof.

5403 Field-Control Motors.—In the case of field-control motors, characteristic curves shall be given for all operating field connections.

TABLE 505.

Approximate Losses in D-C. Railway Motors.

Input in per cent of that at nominal rating	Losses as per cent of input
100 or over	5.0
75	5.0
60	5.3
50	6.5
40	8.8
30	13.3
25	17.0

The core loss of railway motors may also be determined as specified for other machines.

SELECTION OF RAILWAY MOTOR FOR SPECIFIED SERVICE

5501. Data Required in Selecting Motor.—The following information relative to the service to be performed, is required, in order that an appropriate motor may be selected.

(a) Weight of total number of cars in train (in tons of 2000 lb.) exclusive of electrical equipment and load.
(b) Average weight of load and durations of same, and maximum weight of load and durations of same.
(c) Number of motor cars or locomotives in train, and number of trailer cars in train.
(d) Diameter of driving wheels.
(e) Weight on driving wheels, exclusive of electrical equipment.
(f) Number of motors per motor car.
(g) Voltage at train with power on the motors—average, maximum and minimum.
(h) Rate of acceleration in miles per hour per second.
(i) Rate of braking (in miles per hour per second).
(j) Speed limitations, if any (including slowdowns).
(k) Distances between stopping points.
(l) Average duration of stops.
(m) Schedule speed, including stops, in miles per hour.
(n) Train resistance in pounds per ton of 2000 pounds at stated speeds.
(o) Moment of inertia of revolving parts, exclusive of electrical equipment.
(p) Profile and alignment of track.
(q) Distance coasted as a percentage of the distance between stopping points.
(r) Duration of layover at end of run, if any.

5502* Method of Comparing Motor Capacity with Service Requirements.—When it is not convenient to test motors under actual specific service conditions, recourse may be had to the following method of determining temperature rise from the stand-tests.

The essential motor losses affecting temperatures in service are those in the motor windings, core and commutator. The mean service conditions may be expressed, as a close approximation, in terms of that continuous current and core loss which will produce the same losses and distribution of losses as the average in service.

(5502) Calculation for comparing motor capacity with service requirements. The heating of a motor should be determined, wherever possible, by testing it in service, or with an equivalent duty-cycle. When the service or equivalent duty-cycle tests are not practicable, the ratings of the motor may be utilized as follows to determine its temperature rise.

The motor losses which affect the heating of the windings are as stated above, those in the windings and in the core. The former are proportional to the square of the current. The latter vary with the voltage and current, according to curves which can be supplied by the manufacturers. The procedure is therefore as follows:

(a) Plot a time-current curve, a time-voltage curve, and a time-core loss curve for the duty-cycle which the motor is to perform, and calculate from these the root-mean-square current and the average core loss.

(b) If the calculated r.m.s. service current exceeds the continuous rating, when run with

A stand test with the current and voltage which will give losses equal to those in service, will determine whether the motor has sufficient capacity to meet the service requirements. In service, the temperature rise of an enclosed motor (§4044), well exposed to the draught of air incident to a moving car or locomotive, will be from 75 to 90 per cent (depending upon the character of the service) of the temperature rise obtained on a stand test with the motor completely enclosed and with the same losses. With a ventilated motor (§4045 and §4046), the temperature rise in service will be 90 to 100 per cent of the temperature rise obtained on a stand test with the same losses.

In making a stand test to determine the temperature rise in a specific service, it is essential in the case of a self-ventilated motor (§4046) to run the armature at a speed which corresponds to the schedule speed in service. In order to obtain this speed it may be necessary, while maintaining the same total armature losses, to change somewhat the ratio between the I^2R and core-loss components.

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average service core loss and speed, the motor is not sufficiently powerful for the duty-cycle contemplated.

(c) If the calculated r.m.s. service current does not exceed the continuous rating, when run with average service core loss and speed, the motor is ordinarily suitable for the service.

In some cases, however, it may not have sufficient thermal capacity to avoid excessive temperature rises during the periods of heavy load. In such cases a further calculation is required, the first step of which is to compute the equivalent voltage which, with the r.m.s. current, will produce the average core loss. Having obtained this, determine, as follows, the temperature rise due to the r.m.s. service current and equivalent voltage.

$$\text{Let } \left.\begin{aligned} t &= \text{temperature rise} \\ p_0 &= I^2R \text{ loss, kw.} \\ p_c &= \text{core loss, kw.} \end{aligned}\right\} \text{with r.m.s. service current, and equivalent service voltage.}$$

$$\left.\begin{aligned} T &= \text{temperature rise} \\ P_0 &= I^2R \text{ loss, kw.} \\ P_c &= \text{core loss, kw.} \end{aligned}\right\} \text{with continuous load current corresponding to the equivalent service voltage.}$$

Then

$$t = T\,\frac{p_0+p_c}{P_0+P_c}\text{, approximately.}$$

(d) The thermal capacity of a motor is approximately measured by the ratio of the electrical loss in kw. at its nominal (one-hour) capacity, to the corresponding maximum observable temperature rise during a one hour test starting at ambient temperature.

(e) Consider any period of peak load and determine the electrical losses in kilowatt-hours during that period from the *electrical* efficiency curve. Find the excess of the above losses over the losses with r.m.s. service current and equivalent voltage. The excess loss, divided by the coefficient of thermal capacity, will equal the extra temperature rise due to the peak load. This temperature rise added to that due to the r.m.s. service current, and equivalent voltage, gives the total temperature rise. If the total temperature rise in any such period exceeds the safe limit, the motor is not sufficiently powerful for the service.

(f) If the temperature reached, due to the peak loads, does not exceed the safe limit, the motor may yet be unsuitable for the service, as the peak loads may cause excessive sparking and dangerous mechanical stresses. It is, therefore, necessary to compare the peak loads with the short-period overload capacity. If the peaks are also within the capacity of the motor, it may be considered suitable for the given duty-cycle.

CONSTRUCTION

5601* **Standard Height of Trolley Wire on Street and Interurban Railways.**—It is recommended that supporting structures shall be of such height that the lowest point of the trolley wire shall be at a height of 18 feet (5.5 m.) above the top of rail under conditions of maximum sag, unless local conditions prevent. On trackage operating electric and steam road equipment and at crossings over steam roads, it is recommended that the trolley wire shall be not less than 21 feet (6.4 m.) above the top of rail, under conditions of maximum sag.

5602 **Standard Gage of Third Rails.**—The gage of third rails shall be not less than 26 inches (66 cm.) and not more than 27 inches (68.6 cm.)

5603 **Standard Elevation of Third Rails.**—The elevation of third rails shall not be less than 2¾ inches (7 cm.) and not more than 3½ inches (8.9 cm.)

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(5601) **A. E. R. A. Standard.**

CHAPTER VI.

STANDARDS FOR TRANSFORMERS AND OTHER STATIONARY INDUCTION APPARATUS

Wherever the General Standards in Chapters II and III apply to transformers they are referred to in the following Chapter by cross references.

Certain rules applying exclusively to railway machinery have, for convenience, been placed in Chapter V with cross reference in all cases to this Chapter. Rules in Chapter VI apply to railway machinery except as they are modified by the rules in Chapter V.

Note: The work "Transformer" will be used throughout this Chapter as an abbreviation of "Transformer or other stationary induction apparatus."

DEFINITIONS

Apparatus

6000 **Stationary Induction Apparatus.**—For the purpose of these Standards stationary induction apparatus is defined as electric apparatus which changes electric energy to electric energy through the medium of magnetic energy, without mechanical motion. It comprises several forms, as defined in §§ **6001** and **6010** to **6015**.

6001 **Transformer.**—A transformer is a form of stationary induction apparatus in which the primary and secondary windings are ordinarily insulated one from another.

6010 **Auto-Transformer.**—An auto-transformer is one which has a part of its turns common to both primary and secondary circuits.

6011 **Voltage-Regulator.**—A voltage-regulator is a form of stationary induction apparatus which has turns in shunt and turns in series with the circuit, so arranged that the voltage ratio of the transformation, or the phase relation between the circuit-voltages, is variable at will.

6012 **Contact Voltage Regulator.**—A contact voltage regulator is a voltage regulator in which the number of turns in one or both of the coils is adjustable.

6013 **Induction Voltage Regulator.**—An induction voltage regulator is one in which the relative position of the primary and secondary coils is adjustable.

6014 **Magneto Voltage Regulator.**—A magneto voltage regulator is one in which the direction of the magnetic flux with respect to the coils is adjustable.

6015 **Reactor.**—A reactor is a device used primarily because it possesses the property of reactance. Reactors are used in electric circuits for purposes of operation, protection or control.

Parts of Apparatus

6020 High-Voltage and Low-Voltage Winding.—The terms "high voltage" and "low voltage" are used to distinguish the winding having the greater from that having the lesser number of turns.

6021 Primary and Secondary Windings.—The term "primary" and "secondary" serve to distinguish the windings in regard to energy flow, the primary being that which receives the energy from the supply circuit, and the secondary that which receives the energy by induction from the primary.

Properties of Apparatus

6031 Rated Current of a Constant-Potential Transformer.—The rated current of a constant-potential transformer is that secondary current which, multiplied by the rated-load secondary voltage, gives the kv-a. rated output. That is, a transformer of given kv-a. rating must be capable of delivering the rated output at rated secondary voltage, while the primary impressed voltage is increased to whatever value is necessary to give rated secondary voltage.

6032 Rated Primary Voltage of a Constant-Potential Transformer.—The rated primary voltage of a constant-potential transformer is the rated secondary voltage multiplied by the turn ratio.

6033 Ratio of a Transformer.—The ratio of a transformer, unless otherwise specified, shall be the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding; *i. e.*, the "turn-ratio."

6034 Voltage Ratio of a Transformer.—The voltage ratio of a transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary terminal voltage, under specified conditions of load.

6035 Current Ratio of a Transformer.—The current ratio of a current-transformer is the ratio of the r.m.s. primary current to the r.m.s. secondary current, under specified conditions of load.

6036 Volt-Ampere Ratio of Transformer.—The volt-ampere ratio, which should not be confused with real efficiency, is the ratio of the volt-ampere output to the volt-ampere input of a transformer, at any given power factor.

6050* Per Cent Resistance Drop.—The per cent resistance drop in a transformer is the ratio of the internal resistance drop at 75°C. to the secondary terminal voltage expressed in per cent.

6051* Per Cent Reactance Drop.—The per cent reactance drop in a transformer is the ratio of the internal reactance drop to the secondary terminal voltage expressed in per cent.

6052* Per Cent Impedance Drop.—The per cent impedance drop in a transformer is the ratio of the internal impedance drop at 75°C. to the secondary terminal voltage expressed in per cent.

6053 Regulation of Constant-Potential Transformer.—In constant-potential transformers, the regulation is the difference between the

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(6050-6051-6052) The internal drop in a transformer is the sum of the primary drop (reduced to secondary terms) and the secondary drop.

no-load and rated-load values of the secondary terminal voltage at the specified power factor (with constant primary impressed terminal voltage) expressed in per cent of the rated-load secondary voltage, the primary voltage being adjusted to such a value that the apparatus delivers rated output at rated secondary voltage. See §**3390**.

Ambient Temperature.—See §**3000**.

RATING

General

6201 **TABLE 601**

Limiting Observable Temperatures and Temperature Rises for Transformers Using Class A* Insulation.

	†Air Cooled and Air Blast	Oil Cooled	Water Cooled
Limiting Observable Temperature	95°C.	95°C.	80°C.
Standard Ambient Temperature	40°C.	40°C.	25°C.
Limiting Observable Temperature Rise	**55°C.**	**55°C.**	**55°C.**

The temperature of the windings of transformers is always to be ascertained by Method 2.

*For cotton, silk, paper and similar materials when neither treated, impregnated nor immersed in oil, the limits of the observable temperature rise shall be 15°C. below the limits fixed for these materials when impregnated.

†For exceptions in the case of Air Blast Transformers, see §**6320** (*b*).

6202 Limiting Observable Temperature of Oil (From §**2232**).—The oil in which apparatus is permanently immersed shall, in no part, have a temperature, observable by thermometer, in excess of 90°C.

Permissible Temperatures of Insulations of More Than One Class.—See §**2104**.

Temperatures of Metallic Parts of Transformers.—See §**2116**.

Protection Against Short Circuit.—See §**2120**.

Nominal Rating of Railway Substation Transformers.—See §**5201**.

Expression of Rating.—See §**2202**.

Institute Rating.—See §**2204**.

6204* Rating of Protective Reactors.—Protective reactors shall be rated by the following characteristics:

(*a*) Kilovolt-amperes absorbed by normal current.

(*b*) Normal current, frequency and line (delta) voltage.

(*c*) Current which the device is required to stand under short circuit conditions.

(6204) Reactors shall be so designed as to be capable of withstanding the sudden application, without mechanical injury, of rated current at normal frequency.

Ambient Temperature of Reference

Ambient Temperature of Reference for Air.—See §2211.

Ambient Temperature of Reference for Water-Cooled Transformers.—See §2212.

Transformers Cooled by Other Means.—See §2213.

Outdoor Transformers Exposed to Sun's Rays.—See §2214.

Altitude Correction

Altitude.—See §2215.

6215 **Exception to "Altitude".**—See §2215—Water-cooled oil-immersed transformers are exempt from this reduction.

Units in Which Rating Shall be Expressed

6221 **Rating of Transformers.**—The rating of transformers shall be expressed in kilovolt-amperes (kv-a.) available at the output terminals, at a specified frequency and voltage.

6223 **Rating of Other Stationary Induction Apparatus.**—Other stationary induction apparatus such as auto-transformers, regulators, reactors, etc., shall have their ratings appropriately expressed. It is also essential to specify the voltage and frequency of the circuits on which the apparatus may be used.

Kinds of Rating

Continuous Rating.—See §2220.

Short-Time Rating.—See §2221.

Duty-Cycle Operation,—See §2222.

Standard Short-Time Ratings.—See §2223.

A. I. E. E. and I. E. C. Ratings.—See §2224.

Continuous Rating Implied.—See §2225.

6236 **Nominal Ratings.**—Nominal ratings are ratings which do not conform with § §2220 and 2221. They are sometimes used for railway substation transformers carrying traction loads. Transformers with nominal rating shall be capable of operating under the conditions enumerated in §5201.

Rating by Temperature Rise

Permissible Temperature Rises for Various Ambient Temperatures above Standard.—See §2231 (*d*).

TESTS

Ambient Temperature

Measurement of Ambient Temperatures during Tests of Transformers.—See §2300.

6300 **Measurement of the Ambient Temperature During Tests of Water-Cooled Transformers.**—The temperature rise of water-cooled transformers shall be based entirely upon the temperature of the cooling water and it is not necessary to take into account the heat carried off by the air, unless it exceeds the amount specified below. If under assumed standard conditions of water at 25° C, and air at 40° C, the amount of heat which would be carried off by

the air is 15% or more of the total, the temperature of the cooling water, during test, should be maintained within 5° C. of that of the surrounding air. Where this is impracticable the ambient temperature should be determined from the change in the resistance of the windings, using a disconnected transformer, supplied with the normal amount of cooling water, until the temperature of the windings has become constant.

Oil Cup.—See **§2301.**

Transformer Temperatures

Temperature Rise for Any Ambient Temperature.—See **§2310.**

Correction for the Duration of the Ambient Temperature of the Cooling Medium, at the Time of the Heat Test, from the Standard Ambient Temperature of Reference.—See **§2311.**

6311* **Correction for the Deviation of the Ambient Temperature of the Cooling Medium, at the Time of the Heat Test of Air-Blast Transformers from the Standard Ambient Temperature of Reference.**—A correction shall be applied to the observed temperature rise of the windings of air-blast transformers due to difference in resistance, when the temperature of the ingoing cooling air differs from that of the standard of reference. This correction shall be the ratio of the inferred absolute ambient temperature of reference to the inferred absolute temperature of the ingoing cooling air, *i. e.* the ratio $274.5/(234.5 + t)$; where t is the ingoing cooling-air temperature.

Duration of Temperature Test of Transformers for Continuous Service.—See **§2312.**

Duration of Temperature Test of Transformer with a Short-Time Rating.—See **§2313.**

Duration of Temperature Test for Transformer Having More Than One Rating.—See **§2314.**

Temperature Measurements during Heat Run.—See **§2315.**

6317 **Methods of Loading Transformers for Temperature Tests.** (*a*) *General*: Whenever practicable, transformers should be tested under conditions that will give losses approximating as nearly as possible to those obtained under normal or specified load conditions, maintained for the required time The maximum temperature rises measured during this test should be considered as the observable temperature rises for the given load. See §§**2312** to **2314.**

An approved method of making these tests is the *loading-back* method. The principal variations of this method are given in §**6317** (b,) (c) and (d).

(*b*) *Loading-back with duplicate single-phase transformers*: Duplicate single-phase transformers may be tested in banks of two, with

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(6311) Thus, a cooling-air room temperature of 30° C. would correspond to an inferred absolute temperature of 264.5° on the scale of copper resistivity, and the correction to 40° C. (274.5° inferred absolute temperature) would be 274.5/264.5 = 1.04, making the correction factor 1.04; so that an observed temperature rise of say 50° C. at the testing ambient temperature of 30° C. would be corrected to 50 × 1.04 = 52° C. this being the temperature rise which would have occurred had the test been made with the standard ingoing cooling-air temperature of 40° C.

both primary and secondary windings connected in parallel. Normal magnetizing voltage should then be applied and the required current circulated from an auxiliary source. One transformer can be held under normal voltage and current conditions while the other may be operating under slightly abnormal conditions.

(*c*) *Loading-back with one three-phase transformer*: One three-phase transformer may be tested in a manner similar to §**6317** (*b*) provided the primary and secondary windings are each connected in delta for the test. Normal three-phase magnetizing voltage should be applied and the required current circulated from an auxiliary single-phase source.

(*d*) *Loading-back with three single-phase transformers*: Duplicate single-phase transformers may be tested in banks of three in a manner similar to that described in §**6317** (*c*), by connecting both primary and secondary windings in delta, applying normal three-phase magnetizing voltage and circulating the required current from an auxiliary single-phase source.

(*e*) *Other Methods*: Among other methods that have a limited application and can be used only under special conditions may be mentioned:

Applying dead load by means of some form of rheostat.

Running alternately for certain short intervals of time on open circuit and then on short-circuit, alternating in this way until the transformer reaches a steady temperature. In this test, the voltage for the open-circuit interval and the current for the short-circuit interval shall be such as to give the same integrated core loss, and the same integrated copper loss as in normal operation.

6320 Method of Temperature Measurement.—(*a*) *Description*: The temperature of transformer windings shall be measured by their increase in resistance, corrected to the instant of shut-down when necessary, and by thermometers. Whichever measurement yields the higher temperature, that temperature shall be taken as the highest observable temperature by Method 2.

(*b*) In the case of air-blast transformers, it is important to have the thermometers well distributed and in good contact with the coils, and it is especially important to note the temperature near the air outlet. In measuring the temperature of air-blast transformers, the air supply shall be shut off immediately at the end of the temperature run and the air intake closed to prevent further admission of cooling air. With the above procedure, the observable temperature rise for air-blast transformers may attain a value not in excess of 60°C. as determined by thermometer, although it must not exceed 55°C. as determined by resistance.

(*c*) *Temperature Correction for Cooling of Transformer Windings after Shut-Down*: Since a drop in temperature occurs in a winding between the instant of shut-down and the time of measuring the hot resistance, a correction shall be applied to the temperature determined from this measurement so as to obtain, as nearly as practicable,

the temperature at the instant of shut-down. This correction may be determined approximately by plotting a time-temperature curve with temperatures as ordinates and times as abscissae and extrapolating back to the instant of shut-down.

In cases where successive measurements show increasing temperatures after shut-down the highest value shall be taken.

In certain cases, however, other correction factors may be applied as follows:

Oil-Immersed Transformers: For the purpose of simplifying the application of the rule to transformers when the weight of copper in each winding is known and the copper loss as determined by wattmeter measurement does not exceed 30 watts per lb., the extrapolation method has been reduced to the following form which is recommended on account of the greater accuracy obtainable under ordinary conditions of testing. The correction in degrees C. shall be the product of the watts loss per lb. of copper for each winding multiplied by a factor depending upon the time elapsed between shut-down and the time of the temperature reading as given in the following table:

Time in Minutes	Factor
1	0.19
2	0.32
3	0.43
4	0.50

For intermediate times, the value of the factor can be obtained by interpolation.

When the copper loss, measured by wattmeter, does not exceed 7 watts per lb. an arbitrary correction of one degree per minute may be used provided the time elapsed between the instant of shut-down and the measurement of the hot resistance does not exceed 4 minutes.

For determining the copper loss in watts per lb., the total loss in both windings as measured by the wattmeter should be apportioned between the high and low voltage windings in the same ratio as their respective I^2R losses.

Air-Blast Transformers: An arbitrary correction of one degree per minute may be used provided the time elapsed between the instant of shut-down and the measurement of the hot resistance does not exceed four minutes.

(*d*) *Covering of Thermometers*: Thermometers used for taking the temperature of air-cooled or air-blast transformers shall have their bulbs covered for protection from air currents. This shall be done by felt pads, approximately 4 cm. x 5 cm. (1 1/2 in. x 2 in.) and

3 mm. (1/8 in.) thick, except that where pads are inconvenient, as in ventilating ducts between coils, grooved wooden sticks may be used.

Temperature Coefficient of Copper.—See §**2321.**

Efficiency

Efficiencies Recognized.—See § **2331.**
Normal Conditions for Efficiency Tests.—See § **2332.**
Direct Measurement of Efficiency.—See § **2333.**

6334 Classification of Losses.—(*a*) *General*: Losses are classified as shown below.

(*b*) *No-Load Losses*: No-load losses include the core loss, the I^2R loss due to the exciting current and the dielectric loss in the insulation.

(*c*) *Load Losses*: Load losses include I^2R losses, and stray load-losses due to eddy-currents caused by fluxes varying with load.

6335 Losses to be Considered in Transformers.—Conventional efficiencies shall be based upon the losses listed in §**6334** and these losses shall be measured as specified in §§**6336** and **6337**.

6336 No-Load Losses.—The no-load losses shall be measured with open secondary circuit at the rated frequency, and with an applied primary voltage giving the rated secondary voltage plus the $I\ R$ drop which occurs in the secondary under rated load conditions.

6337 Load Losses.—The load losses include I^2R and stray load-losses. They shall be measured by applying a primary voltage, at rated frequency, sufficient to produce rated load current in the windings, with the secondary windings short-circuited.

Wave Shape

Standard Wave Shape.—See § **2340.**

Tests of Dielectric Strength

Condition of Transformers to be Tested.—See §**2350.**
Where High Voltage Tests are to be Made.—See §**2351.**
Temperature at which High Voltage Tests are to be Made.—See §**2352.**
Points of Application of Voltage.—See §**2353.**
Frequency and Wave Form of Test Voltage.—See §**2354.**
Duration of Application of Test Voltage.—See §**2355.**

6356 Standard Test Voltage.—(From §**2356.**) *General*: The standard test voltage for all machines, except as otherwise specified, shall be twice the normal voltage of the circuit to which the machine is connected plus 1000 volts. See exception §**6361.**

6360 Transformers for Star Connection.—Transformers which may be used in star connection on three-phase circuits shall be tested on the basis of the line to line voltage for which they are rated. See §**6361-f.**

6361* Exceptions to Standard Test Voltage Given in Section 6356.—(*a*) *Distributing Transformers*: Transformers for primary pres-

sures from 550 to 4500 volts, the secondaries of which are directly connected to consumers' circuits and commonly known as distributing transformers, shall be tested with 10,000 volts from primary to core and secondary combined. The secondary windings shall be tested with twice their normal voltage plus 1000 volts.

(*b*) *Auto-Transformers:* Auto-transformers used for starting purposes, shall be tested with the same voltage as the test voltage of the apparatus to which they are connected.

(c) *Household Devices:* Transformers taking not over 660 watts and intended solely for operation on supply circuits not exceeding 275 volts, shall be tested with 900 volts.

* (*d*) *Transformers for Use on Circuits of 25 Volts or Lower*: Transformers for use on circuits of 25 volts or lower, such as bell-ringing apparatus, shall be tested with 500 volts.

(e) *Alternating Current Transformers Connected to Permanently Grounded Single Phase Systems, for use on Permanently Grounded Circuits of more than 300 Volts:* Transformers used under these conditions shall be tested with 2.73 times the voltage of the circuit to ground plus 1000 volts. This does not refer to three-phase transformers operating with grounded neutral.

(f) *Transformers to be used on star-connected three-phase circuits:* Transformers which may be used in star connection on three-phase circuits shall have the line to line (as distinguished from line to neutral) voltage of the circuits on which they may be used indicated on the rating plate and the test shall be based on the line to line voltage. See §**6360.**

(g) *Protective Reactors*: Protective reactors shall be tested from conductors to ground with 2000 volts plus 2¼ times the line voltage.

6362* Testing Transformers by Induced Voltage.—Under certain conditions it is permissible to test transformers by inducing the required voltage in their windings in place of using a separate testing transformer. By "required voltage" is meant a voltage such that the line end of the windings shall receive a test to ground equal to that required by the general rules.

6363 Transformers with Graded Insulation.—Where transformers have graded insulation they shall be so marked. They shall be tested by inducing the required test voltage in the transformer and connecting the successive line leads to ground.

Transformer windings permanently grounded within the transformer shall be tested by inducing the required test voltage in such windings. See §**6361.**

Use of Voltmeter and Spark-gaps in Dielectric Tests.—See §**2359.**

Use of Spark-gap with Transformers of Low Capacitance.—See §**2360.**

Use of Spark-gap with Transformers of High Capacitance.—See §**2361.**

(6361-d) This rule does not include bell-ringing transformers of ratio 125 to 6 volts.

(6362) This test can be made by connecting the windings of two or more transformers in series, with one end of the series grounded and a voltage impressed such as will give the test from the free end to ground required by the above rule.

Measurements with Voltmeter.—See §2362.
Measurements with Spark-gap.—See §2363.

Regulation

Conditions for Tests of Regulation.—See §2390.

6390 **Conditions for Tests of Regulation.**—(*a*) *Frequency*: The regulation of transformers is to be determined at constant frequency.

(*b*) *Power Factor:* In transformers, the power factor of the load to which the regulation refers should be specified. Unless otherwise specified, it shall be understood as referring to non-inductive load, that is, to a load in which the current is in phase with the e.m.f. at the output side of the transformer. See §2390.

6391* **Tests and Computation of Regulation.**—*(a) *Method I. By Loading:* The regulation of a constant potential transformer can be determined by loading the transformer and measuring the change in voltage with change in load, at the specified power factor.

(*b*) *Method II. From Impedance Watts and Volts*: The regulation of a constant potential transformer for any specified load and power factor can be computed from the measured impedance watts and impedance volts as follows:

Let:

P = impedance watts, as measured in the short-circuit test and corrected to 75°C.

E_z = impedance volts, as measured in the short-circuit test.

$I\,X$ = Reactance Drop in Volts.

I = Rated Primary Current.

E = Rated Primary Voltage.

q_r = per cent drop in phase with current.

q_x = per cent drop in quadrature with current.

$$I\,X = \sqrt{E_z^2 - \left(\frac{P}{I}\right)^2}$$

$$q_r = 100\,\frac{P}{E\,I}$$

$$q_x = 100\,\frac{I\,X}{E}$$

Then—

For *unity power factor*, we have approximately,

$$\text{Per cent regulation} = q_r + \frac{q_x^2}{200}$$

For *inductive loads* of power-factor m and reactive-factor n,

$$\text{Per cent regulation} = m\,q_r + n\,q_x + \frac{(m\,q_x - n\,q_r)^2}{200}$$

(6391 a) This method is not generally applicable for shop tests, particularly on large transformers.

CONSTRUCTION

Rating Plates

Marking of Rating Plates.—See §2401.

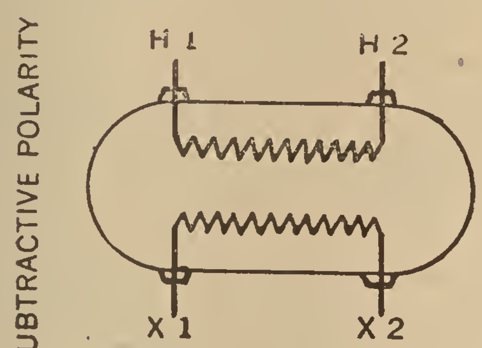
Transformer Connections

(*These rules do not apply to auto-transformers*)

General

6402* **Scope.**—These rules specify the markings of leads brought out of the case but not the markings of winding terminals inside of the case, except that these terminals shall be marked with numbers in any manner that will permit of convenient reference and that cannot be confused with the markings of the leads brought out of the case.

TRANSFORMER LEAD MARKINGS SINGLE PHASE TRANSFORMERS



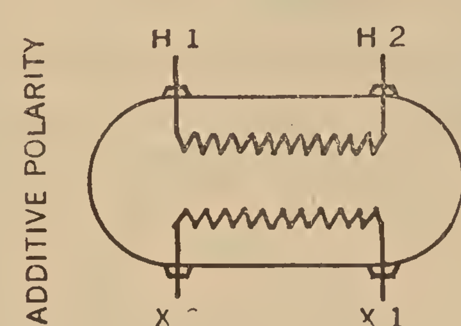
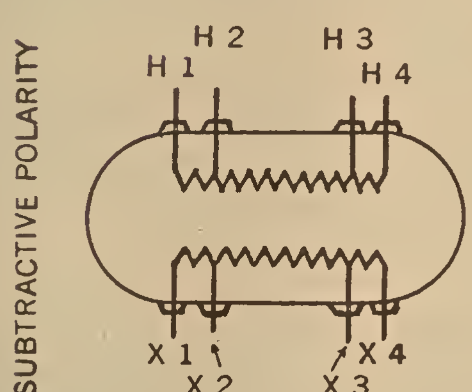


FIG. 6-1 FIG. 6-2

Simple High and Low-Voltage Windings Without Taps



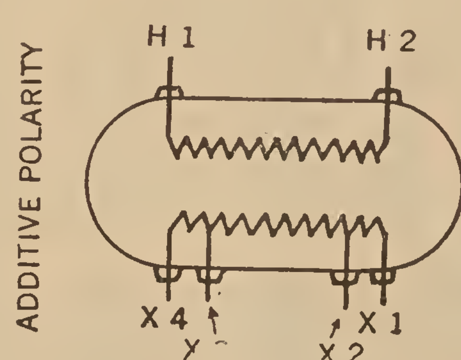


FIG. 6-5 FIG. 6-4

Simple High and Low-Voltage Windings With Taps

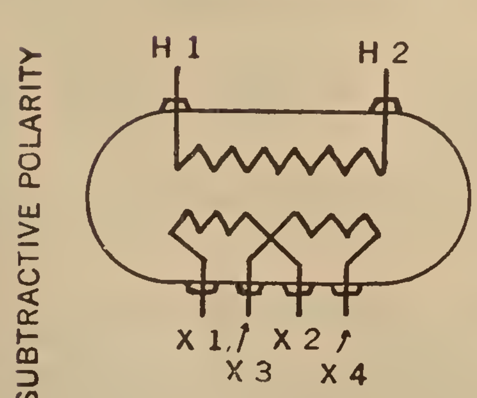


FIG. 6-3

Series Multiple Low-Voltage Winding Without Taps

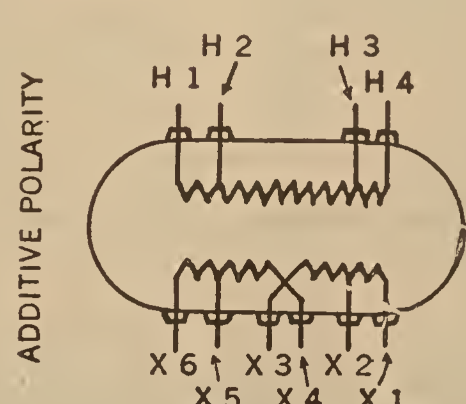


FIG. 6-6

Series Multiple Low-Voltage Winding With Taps

NOTE:—The above figures illustrate the application of the rules on lead markings to transformers having subtractive and additive polarity.

(6402) It is recognized that special cases will arise from time to time that these rules will not cover and that it would be very difficult to cover by any set of general rules.

6403* **Markings of Leads.**—*(*a*) *General:* The leads shall be distinguished from one another by marking each lead with a capital letter followed by a number. The letters to be used are: *H* for high voltage leads, *X* for low voltage leads and *Y* for tertiary winding leads. The numbers to be used are 1, 2, 3, etc.

*(*b*) *Neutral Lead:* A neutral lead shall be marked with the proper letter followed by *O*, *e.g.*, *HO*, *XO*.

6404 **Diagrammatic Sketch of Connections.**—The manufacturer shall furnish with each transformer a complete diagrammatic sketch showing the leads and internal connections and their markings and the voltages obtainable with the various connections.

This sketch should preferably be on a metal plate attached to the transformer case.

Single-Phase Transformers

6405 **Order of Numbering Leads in any Winding.**—The leads of any winding (high-voltage, low-voltage or tertiary) brought out of case shall be numbered 1, 2, 3, 4, 5, etc., the lowest and highest numbers marking the full winding and the intermediate numbers marking fractions of winding or taps. All numbers shall be so applied that the potential difference from any lead having a lower number toward any lead having a higher number shall have the same sign at any instant.

If a winding is divided into two or more parts for series parallel connections, and the leads of these parts are brought out of case, the above rule shall apply for the series connection with the addition that the leads of each portion of winding shall be given consecutive numbers. See Figs. 6-5 and 6-6.

6406 **Relation of Order of Numbering Leads of Different Windings.** The numbering of the high-voltage and low-voltage leads shall be so applied that when H_1 and X_1 are connected together and voltage applied to the transformer, the voltage between the highest numbered *H* lead and the highest numbered *X* lead shall be less than the voltage of the full high-voltage winding.

The same relation shall apply between high-voltage and tertiary and low-voltage and tertiary winding.

6407 **Polarity.**—When leads are marked in accordance with the above rules, the polarity of a transformer is

Subtractive when H_1 and X_1 are adjacent. See Figs. 6-1, 6-3 and 6-5.

(6403-a) By "tertiary winding" is meant a third winding that, compared with both of the other two windings, has smaller kv-a. rating than either or, if the kv-a. rating is the same as one or both of the other two, has lower voltage. *E. g.*, if a transformer has three separate windings, one for 1000 kv-a., 33,000 volts, one for 600 kv-a., 550 volts and one for 400 kv-a. 6,600 volts, the 400 kv-a. winding is the tertiary winding; or, if a transformer has three separate windings each with a capacity of 1,000 kv-a., and with voltages of 33,000, 6600 and 550 respectively, the 550 volt winding is the tertiary winding.

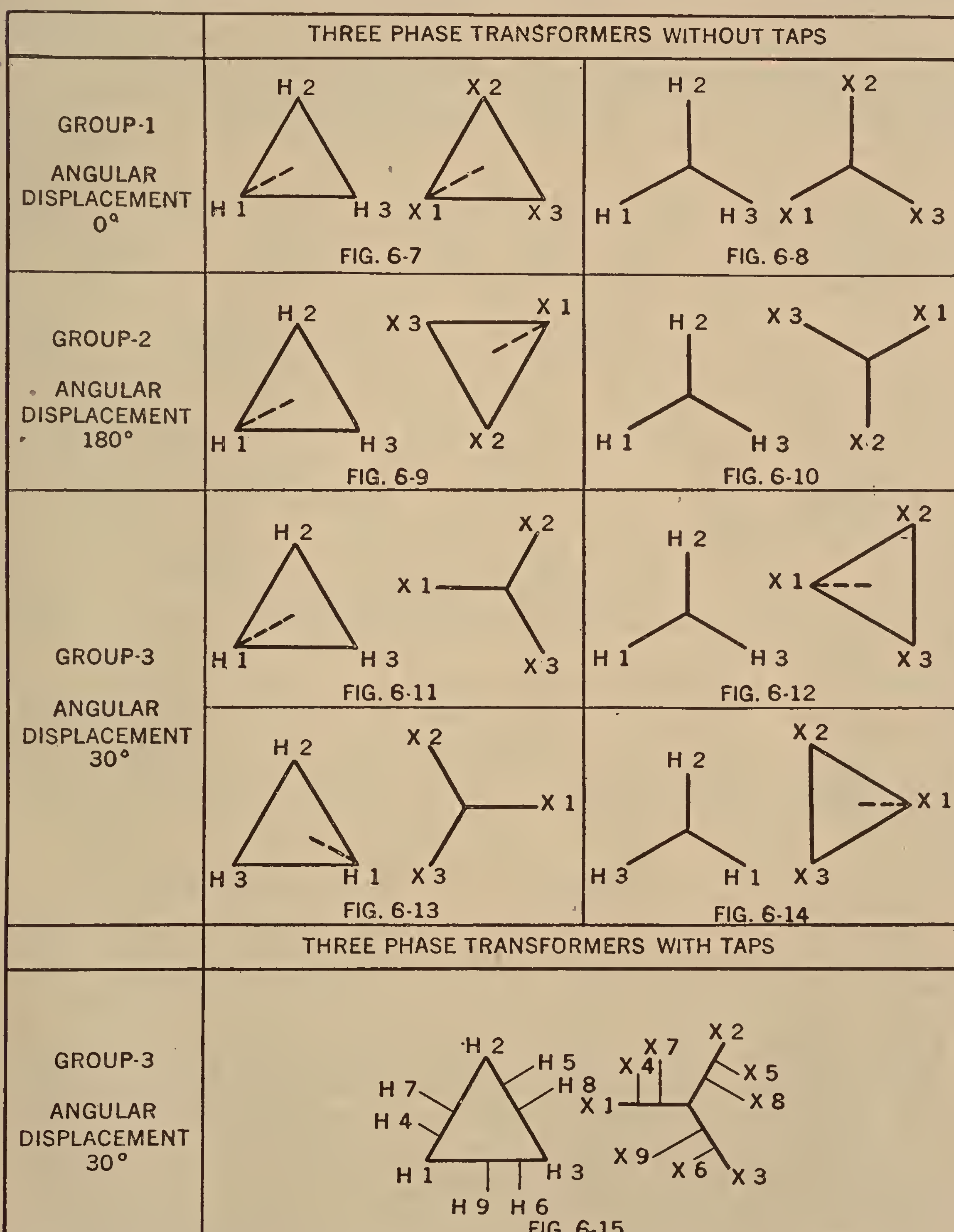
According to this definition neither one of two similar windings arranged for series-parallel connection is to be classed as a tertiary winding.

(6403-b) A lead brought out from the middle of a winding for some other use, than that of neutral lead, *e.g.*, a 50 per cent starting tap, shall be marked as a tap lead.

Additive when H_1 is diagonally located with respect to X_1. See Figs. 6-2, 6-4 and 6-6.

6408 **Location of H_1 Lead.**—To simplify the work of connecting transformers in parallel it is recommended that the H_1 lead shall be brought out on the right hand side of the case, facing high-voltage side of the case.

TRANSFORMER LEAD MARKINGS AND VOLTAGE VECTOR DIAGRAMS FOR THE USUAL THREE PHASE TRANSFORMER CONNECTIONS



NOTE:—The above figures are included to illustrate the method of marking transformer leads that are brought out of the case and are not intended to standardize connections, vector diagrams or polarity.

6409* **Parallel Operation.**—Transformers having leads marked in accordance with these rules may be operated in parallel by connecting similarly marked leads together, provided their ratio, voltages, resistances and reactances are such as to permit parallel operation.

Three-Phase Transformers

6410 **Marking of Full Winding Leads.**—The three high-voltage leads and the three low-voltage leads which connect to the full-phase windings, shall be marked H_1, H_2, H_3, and X_1, X_2, X_3. The full-phase winding of a tertiary winding shall be marked Y_1, Y_2, Y_3.

TRANSFORMER LEAD MARKINGS AND VOLTAGE VECTOR DIAGRAMS FOR THE USUAL SIX-PHASE TRANSFORMER CONNECTIONS

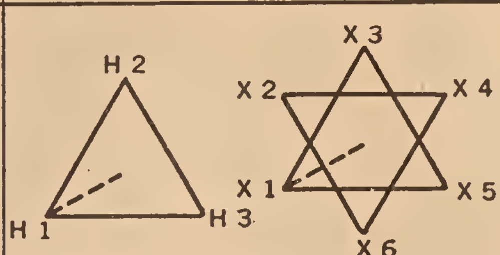
<table>
<tr><td></td><td colspan="2">SIX PHASE TRANSFORMERS WITHOUT TAPS</td></tr>
<tr><td>GROUP-4
ANGULAR DISPLACEMENT 0°</td><td>

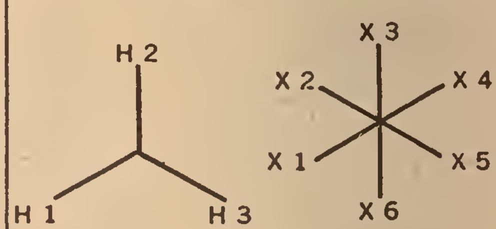
FIG. 6-16</td><td>

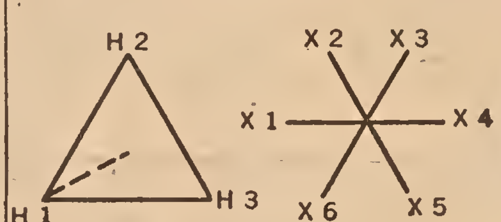
FIG. 6-17</td></tr>
<tr><td>GROUP-5
ANGULAR DISPLACEMENT 30°</td><td>

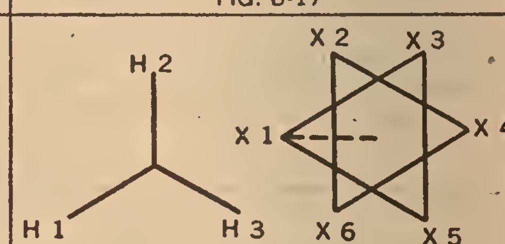
FIG. 6-18</td><td>

FIG. 6-19</td></tr>
<tr><td></td><td colspan="2">SIX PHASE TRANSFORMERS WITH TAPS</td></tr>
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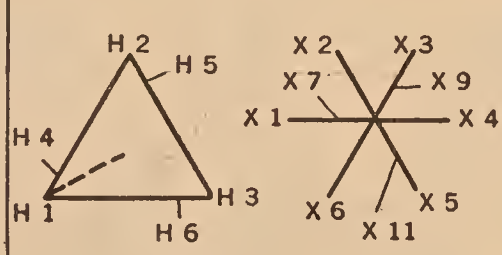
ANGULAR DISPLACEMENT 30°</td><td>

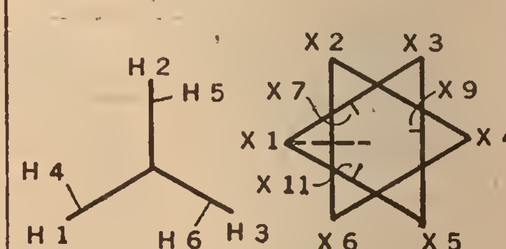
FIG. 6-20</td><td>

FIG. 6-21</td></tr>
</table>

NOTE:—The above figures are included to illustrate the method of marking transformer leads that are brought out of the case and are not intended to standardize connections, vector diagrams or polarity.

6411* **Relation between High-Voltage and Low-Voltage Windings.**—(*a*) *General:* The markings shall be so applied that if the phase sequence of voltage on the high voltage side is in the time order H_1, H_2, H_3 it is in the time order of, X_1, X_2, X_3 on the low-voltage side and Y_1, Y_2, Y_3 for a tertiary winding.

(6409) In some cases design may be such as to permit parallel operation, although due to the difference in the number of tap leads, the leads to be connected together may not have the same number.

*(*b*) *Angular Displacement:* In order that the markings of lead connections between phases shall indicate definite phase relations, they shall be made in accordance with one of the three three-phase groups as shown. The angular displacement between the high-voltage and low-voltage windings is the angle in each of the voltage vector diagrams (Figs. 6-7 to 6-14 inclusive) between the lines passing from its neutral point through H_1 and X_1 respectively.

6412 Tap Leads.—(*a*) *General:* Where tap leads are brought out of the case (neutral lead excepted) they shall be marked with the proper letter followed by the numbers 4, 7, etc., for one phase, 5, 8, etc., for another phase and 6, 9, etc., for the third phase. See Fig 6-15.

(*b*) *Delta Connection:* The order of numbering tap leads shall be as follows: 4, 7, etc., from lead 1 toward lead 2; 5, 8, etc., from lead 2 toward lead 3; and 6, 9, etc., from lead 3 toward lead 1. See Fig. 6-15.

(c) *Star Connection:* The order of numbering tap leads shall be as follows: 4, 7, etc., from lead 1 towards neutral; 5, 8, etc., from lead 2 towards neutral; and 6, 9, etc., from lead 3 towards neutral. See Fig. 6-15.

6413 Interphase Connection made Outside of Case.—Where the interphase connections are made outside of case, the leads shall be marked with the proper letter followed by the numbers 1, 4, 7, 10, etc., for one phase; 2, 5, 8, 11, etc., for the second phase; and 3, 6, 9, 12, etc., for the third phase.

The markings shall be so applied that when a star connection is made by joining together the highest numbered leads of each phase, all rules here given, excepting §**6403** (b) apply.

6414* Parallel Operation.—Transformers having leads marked in accordance with these rules may be operated in parallel by connecting similarly marked leads together provided their angular displacements are the same and provided also their ratios, voltages, resistances, and reactances are such as to permit parallel operation.

6415 Location of H1 Lead.—To simplify the work of connecting transformers in parallel it is recommended that the *H 1* lead shall be brought out on the right hand side of the case, facing the high-voltage side of the case.

Three-Phase to Six-Phase Transformers.

6416 Rules that are Applicable for Three-Phase Transformers.—Sections **6411** (b) and **6413** shall apply to three-phase to six-phase transformers.

(6411-b) Any three phase transformer having a delta Y connection may be represented by voltage vector diagram either in accordance with Fig. 6-11 or Fig. 6-13. Any three phase transformer having Y delta connection may be represented by voltage vector diagram either in accordance with Fig. 6-12 or Fig. 6-14. Since these voltage vector diagrams are equivalent, it is recommended that the terminal markings for three phase transformers having delta Y connection be always made in accordance with Fig. 6-11 and that the terminal markings for three phase transformers having Y delta connection be always made in accordance with Fig. 6 12.

(6414) In some cases designs may be such as to permit parallel operation although, due to a difference in the number of tap leads, the leads to be connected together are not similarly marked.

Rules **6410** and **6412** shall apply to three-phase windings but not to six-phase windings.

6417 Markings of Six-Phase Leads.—The six leads which connect to the full-phase windings shall be marked *X1*, *X2*, *X3*, *X4*, *X5*, *X6*. See Figs. 6-16 to 6-19 inclusive.

6418 Relation between Three-Phase and Six-Phase Windings.—(*a*) *General:* The markings shall be so applied that if the phase sequence of voltage on the three-phase side is in the time order *H1*, *H2*, *H3*, it is in the time order of *X1*, *X2*, *X3*, *X4*, *X5*, *X6* on the six-phase side.

(*b*) *Angular Displacement:* In order that the markings of lead connections between phases shall indicate definite phase relations, they shall be made in accordance with one of the four six-phase groups shown in Figs. 6-16 to 6-19 inclusive. The angular displacement between the high-voltage and low-voltage windings is the angle in each of the voltage vector diagrams from its neutral through *H1* and *X1* respectively.

6419* Tap Leads.—(*a*) *General:* Where tap leads from low-voltage windings are brought out of the case (neutral lead excepted), they shall be marked as follows:

(*b*) *Diametrical Connection:* Diametrical connection tap leads shall be marked from the two ends of each phase winding towards the middle or neutral point in the following order; *X7*, *X13*, etc., from *X1* towards neutral; *X8*, *X14*, etc., from *X2* towards neutral; *X9*, *X15*, etc., from *X3* towards neutral; *X10*, *X16*, etc., from *X4* towards neutral; *X11*, *X17*, etc., from *X5* towards neutral; *X12*, *X18*, etc., from *X6* towards neutral. See Fig. 6-20.

A tap from the middle point of any phase winding, not intended as a neutral, shall be given a number determined by counting from *X1*, *X2* or *X3* and not from *X4*, *X5*, or *X6*; *e.g.*, if the only taps brought out are 50 per cent starting taps, they shall be numbered *X7*, *X8*, and *X9*.

*(c) *Double Delta Connection:* Tap leads shall be marked in the following order; *X7*, *X13*, etc., from *X1* towards *X3*; *X8*, *X14*, etc., from *X2* towards *X4*; *X9*, *X15*, etc., from *X3* towards *X5*; *X10*, *X16*, etc., from *X4* towards *X6*; *X11*, *X17*, etc., from *X5* towards *X1*; *X12*, *X18*, etc., from *X6* towards *X2*. See Fig. 6-21.

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(6419-c) For starting purposes it is generally customary to bring out only two taps from one delta and start three-phase.

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CHAPTER VII.

STANDARDS FOR SWITCHING, CONTROL AND PROTECTIVE APPARATUS

The A. I. E. E. Standards for Switching Control and Protective Apparatus are the General Standards shown in Chapters II and III and the Standards in other Chapters which are applicable to the devices involved, together with the modifications and extensions given in this Chapter.

DEFINITIONS

Devices

7000* Switching and Control Apparatus.—For the purpose of these Standardization Rules switching and control apparatus is defined as electric apparatus whose function is primarily to control or protect in some predetermined manner electric apparatus to which it is connected.

7001 Switch.—A switch is a device for making, breaking or changing the connections in an electric circuit.

7002 Master-Switch.—A master-switch is a switch which serves to govern the operation of contactors and auxiliary devices of an electric controller.

7003 Control Switch.—A control switch is a switch for controlling electrically-operated switches and circuit breakers.

7004 Auxiliary Switch.—An auxiliary switch is a switch actuated by some main device, for signalling, interlocking, etc.

7005 Circuit-Breaker.—A circuit-breaker is a device (other than a fuse) constructed primarily for the interruption of a circuit under *infrequent abnormal* conditions.

7006 Contactor.—A contactor is a device for repeatedly establishing and interrupting an electric circuit under normal conditions.

7007* Electric Controller.—An electric controller is a device, or group of devices, which is designed to control in some predetermined manner the operation of the apparatus to which it is connected.

7008* Motorstarter.—A motorstarter is an electric controller designed for accelerating a motor to normal speed in one direction of rotation.

7009 Automatic Motorstarter.—An automatic motorstarter is a motorstarter designed to automatically control the acceleration of a motor.

(7000) The "National Electrical Code" of the National Fire Protection Association deals with certain circuit breakers up to 550 volts rating and switches and fuses up to 600 volts rating fuses.

(7007) A switch (see §7001) should not be called a controller.

(7008) A device designed for starting a motor in either direction of rotation is called a controller (see §7007).

7010 Auto-Transformer Motorstarter.—An auto-transformer motor-starter is a motor-starter having an auto-transformer to furnish a reduced voltage for starting. The device includes the necessary switching mechanism, and is frequently called a Compensator or Auto-Starter.

7015* **Fuse.**—A fuse is an element designed to melt or dissipate at a predetermined current value, and intended to protect against abnormal conditions of current.

7016 Relay.—A relay is a device by means of which contacts in one circuit are operated by change in conditions in the same or other circuits.

7018 Rheostat.—A rheostat is a resistor which is provided with means for readily varying its resistance. See §**3064**.

7019 Protective Reactor.—A protective reactor (See §**3078**) is a device for protecting circuits by limiting the current flow and localizing the disturbance under short circuit conditions.

7020* **Lightning Arrester.**—A lightning arrester is a device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration.

7021 Under-Voltage or Low-Voltage Release Switching and Control Apparatus.—Under-voltage or low-voltage release switching and control apparatus is apparatus which, on the reduction or failure of voltage, operates to cause the interruption of power to the main circuit, but which does not prevent the re-establishment of the main circuit on return of voltage.

7022 Under-voltage or Low-Voltage Protection Switching and Control Apparatus.—Under-voltage or low-voltage protection switching and control apparatus is apparatus which, on the reduction or failure of voltage, operates to cause and maintain the interruption of power to the main circuit.

7023 Phase-Failure Protection Switching and Control Apparatus.—Phase-failure protection switching and control apparatus is apparatus which, on the failure of power in one wire of a polyphase circuit, operates to cause and maintain the interruption of power on the circuit.

7024 Phase-Reversal Protection Switching and Control Apparatus.—Phase-reversal protection switching and control apparatus is appara-

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(7015) Any terminals, tubes, etc., integral with this element are included as part of the fuse.

Fuses may be divided into two classes:

(a) Those designed to protect the circuit and apparatus both against short-circuit and against definite amounts of overload (*e. g.* fuses of the National Electric Code which open on 25 per cent overload.)

(b) Those designed to protect the system only against short circuits; (*e. g.* expulsion fuses, which blow at several times the current which they are designed to carry continuously). The line separating these two classes is not definitely fixed.

(7020) Lightning arresters may be divided into two classes:

(a) Those intended to discharge for a very short time.

(b) Those intended to discharge for a period of several minutes.

tus which, on the reversal of the phase relations in a polyphase circuit, operates to cause and maintain the interruption of power on the circuit.

Characteristics of Devices

7030 **"Air" as a Prefix.**—The prefix "air" applied to a device which interrupts an electric circuit indicates that the interruption occurs in air.

7031 **"Oil" as a Prefix.**—The prefix "oil" applied to a device which interrupts an electric circuit indicates that the interruption occurs in oil.

7032 **Fume-Resisting.**—Fume-resisting switching and control apparatus is apparatus so constructed that it will not be readily injured by the specified fumes.

7033* **Drip-Proof.**—Drip-proof switching and control apparatus is apparatus so protected as to exclude falling moisture or dirt.

7034 **Dust-Proof.**—Dust-proof switching and control apparatus is apparatus so constructed or protected that the accumulation of dust within or without the device will not interfere with its successful operation.

7035 **Dust-Tight.**—Dust-tight switching and control apparatus is apparatus so constructed that the dust will not enter the enclosing case.

7036 **Explosion-Proof.**—Explosion-proof switching and control apparatus is apparatus so constructed that explosions of gas within the casing will not injure it or ignite inflammable gas outside it.

7037 **Gas-Proof.**—Gas-proof switching and control apparatus is apparatus so constructed or protected that the specified gas will not interfere with its successful operation.

7038 **Gas-Tight.**—Gas-tight switching and control apparatus is apparatus so constructed that the specified gas will not enter the enclosing case.

7039 **Moisture-Resisting.**—Moisture-resisting switching and control apparatus is apparatus so constructed or treated that it will not be readily injured by moisture. (Such apparatus shall be capable of operating in a very humid atmosphere, such as found in mines, evaporating rooms, etc.).

7040 **Splash-Proof.**—Splash-proof switching and control apparatus is apparatus so constructed or protected that external splashing will not interfere with its successful operation.

7041 **Submersible.**—Submersible switching and control apparatus is apparatus so constructed that it will operate successfully when submerged in water under specified conditions of pressure and time.

7042 **Sleet-Proof.**—Sleet-proof switching and control apparatus is apparatus so constructed or protected that the accumulation of sleet will not interfere with its successful operation.

(7033) Drip-proof apparatus may be either open or semi-enclosed, if it is provided with suitable protection integral with the apparatus, or so enclosed as to exclude effectively falling solid or liquid material.

Parts of Devices

7050 Conducting Parts.—Conducting parts of switching and control apparatus are those designed to carry current or which are conductively connected therewith.

7051 Contact.—A contact is a surface common to two conducting parts, united by pressure, for the purpose of carrying current.

7052 Magnet Brake.—A magnet brake is a friction brake controlled by electro-magnetic means.

7053 Grounded Parts.—Grounded parts are those parts which may be considered to have the same potential as the earth.

Properties of Devices.

7060 Interrupting Rating.—Interrupting (breaking or rupturing) rating is a rating based upon the r. m. s. current at normal voltage which the device can interrupt under prescribed conditions at stated intervals a specified number of times.

OPERATION

Temperature Limits

7101* Circuit Breakers, Relays and Switches.—The maximum observable temperature rises of the various parts of circuit breakers, relays and switches shall not exceed the following limits for ambient temperatures up to and including but not greater than 40°C. See **§7301.**

Contacts in air, when clean and bright	30°C.
Oil and contacts therein	30°C.
Coils, if insulation is of unimpregnated fibrous material	35°C.
Coils, if insulation is of fibrous material treated to withstand heat	50°C.
Coils, if insulation is of asbestos, mica or similar heat resisting material	70°C.

Coils on which a thermometer can be applied directly to the surface of the bare winding, such as those having bare edgewise strip conductors, shall be allowed 10°C. higher maximum observable temperature rise than permitted above for each kind of insulation.

Other parts: All other parts than those whose temperature affects the temperature of the insulating material may be operated at such temperatures as shall not be injurious in any other respect.

7102 Magnetic Contactors.—The maximum observable temperature rises of the various parts of magnetic contactors shall not exceed the following limits for ambient temperatures up to and including but not greater than 40° C. See §**7302.**

Laminated contacts	65°C.
Operating coils	70°C.
Solid contacts	100°C.

(7101) The Institute calls attention to the inherent decrease in current which can be carried by switch and circuit breaker contacts in air, due to oxidization of the contact surfaces. The rating of air switches and circuit-breakers is, therefore, based on sufficient maintenance to keep the temperature rise within the specified limits. Relays which form part of controllers are to have the temperature limits specified in §7102.

Current-carrying parts insulated with asbestos or other fireproof material.................................... 150°C.

7105* **Fuses.**—The maximum observable temperature rise of coils or windings, measured by thermometer, shall not exceed the following limits for ambient temperatures up to and including but not greater than 40°C.

If insulation is of unimpregnated fibrous material......... 35°C.
If insulation is of fibrous material treated to withstand heat 50°C.
If insulation is of asbestos, mica or similar heat resisting material with a cotton binder.......................... 70°C.

7106 **Cast Grid Resistors.**—The maximum observable temperature rises of cast grids used as resistors shall not exceed 350°C. for ambient temperatures up to and including but not greater than 40°C.

RATING

Expression of Rating

7201 **Rating of Circuit Breakers and Switches.**—The rating of a circuit breaker or switch shall include the following items:

(a) the normal r. m. s. current which it is designed to carry.
(b) the normal r. m. s. pressure (voltage) of the circuit on which it is intended to operate.
(c) the normal frequency of the current.
(d) the interrupting rating of the device. See §**7060**.

7202 **Continuous Current-Carrying Capacity of Fuses.**—Fuses shall be so constructed that they will carry continuously 110 per cent of their rated current.

7205 **Rating of Lightning Arresters.**—The rating of a lightning arrester shall be the voltage of the circuit on which it is to be used.

TESTS

Heat Tests

7301 **Circuit-Breakers, Relays and Switches.**—The rated current of circuit-breakers, relays and switches at rated frequency shall be applied continuously until the temperature becomes constant. The temperature rises measured by thermometer shall not exceed the limits specified in §**7101**.

7302 **Magnetic Contactors.**—The rated current of magnetic contactors at rated frequencies shall be applied continuously or until the temperature becomes constant when continuous duty is specified. It shall be applied for the specified length of time when given a short time rating. The temperature rises measured by thermometer shall not exceed the limits specified in §**7102**.

Tests of Dielectric Strength

7323* **Standard Test Voltage.**—(*a*) *Apparatus rated at* 600 *volts or less*: The standard test voltage for all switching and control apparatus

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(7105) Coils or windings such as accompany fuses of the magnetic blow-out type.

(7323) This assumes a precipitation of 1/10th inch (2.54 mm.) per minute at an angle of 45° from the perpendicular with water having a resistivity as low as 7000 ohm-centimeters.

rated at 600 volts or less shall be twice the normal voltage of the circuit to which the apparatus is to be connected plus 1000 volts.

(*b*) *Apparatus rated above* 600 *volts*: Apparatus rated above 600 volts shall be tested at 2¼ times rated voltage, plus 2000 volts, at a specified altitude.

*As a supplementary test, devices for outdoor use should be capable of withstanding for 10 seconds a dielectric wet test at twice rated voltage plus 1000 volts.

(*c*) *Auto-Transformers for Motorstarters*: Auto-transformers for motorstarters shall be tested with the same voltage as the test voltage of the apparatus to which they are to be connected.

Tests of Lightning Arresters.

7371 Resistance.—The resistance of the arrester at double potential and also at normal potential, shall be determined by observing the discharge currents through the arrester.

7372 Arrester with Gap.—In the case of any arrester using a gap, a test shall be made of the spark potential on either direct-current or 60 cycle a-c. excitation.

7373 Equivalent Sphere Gap.—The equivalent sphere gap under disruptive discharge shall be measured, using a considerable quantity of electricity.

7374 Continuous Surges.—The endurance of the arrester to continuous surges shall be tested.

7375 Dielectric Strength.—See §§ **2355** and **7323**.

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CHAPTER VIII.

STANDARDS FOR METERS, INSTRUMENTS AND INSTRUMENT TRANSFORMERS

The A. I E. E. Standards for Meters, Instruments and Instrument Transformers are the General Standards shown in Chapters II and III, and the Standards in other Chapters which are applicable to the devices involved, together with the modifications and extensions given in this Chapter.

DEFINITIONS.

8000* **Meter.** A meter is a device which registers through a totalizing mechanism, the integral, with respect to time, of the electrical quantity to which it responds. (This definition does not preclude the general use of "meter" as a suffix or in compound words, to mean a "measuring device.")

8001* **Instrument.** An instrument is a device which indicates or records the present value of the quantity under observation.

8002 **General Nomenclature.** In general, the names of meters and instruments are self-defining. The following names are preferred to others sometimes used for the same devices: Reactive-Factor Meter, Power-Factor Meter, Watthour Meter, Reactive Volt-Ammeter (or Reactive Volt-Ampere Indicator) etc.

8003 **Recording Instruments.** Recording ammeters, voltmeters, wattmeters, etc. are instruments which record graphically, upon time charts, the values of the quantities they measure.

8004 **Crest Voltmeter.** A crest voltmeter is a voltmeter depending for its indications upon the crest, or maximum value of the voltage of the system to which it is connected. Crest voltmeters shall be marked in true crest volts and also in the r. m. s. value of the sinusoidal wave having the same crest value. (See §2362.)

8005 **Synchronoscope (also called a Synchroscope or Synchronism Indicator).** A synchronoscope is a device which indicates synchronism between two machines, and in addition shows whether the incoming machine is fast or slow.

8006 **Line-Drop Voltmeter Compensator.** A line-drop voltmeter compensator is a device used in connection with a voltmeter which causes the latter to indicate the voltage at some distant point of the circuit.

(8000 & 8001) While the word "instrument" is a general term which may properly include indicating, integrating and recording devices, there is a tendency to restrict its use to indicating devices and to recording (graphic or curve drawing) devices. Integrating devices are then denoted by the word "meter." This distinction gives rise to the above general definitions.

8007 Demand-Meter. (a) *General*: A demand-meter is a device which indicates or records the demand or maximum demand. In practise, two types are recognized. See §§ **3454, 3458, 3460** and **3464.**

(*b*) *Integrated-Demand-Meter*: An integrated-demand-meter is a demand-meter which indicates or records the maximum demand obtained through integration.

(*c*) *Lagged-Demand-Meter*: A lagged-demand-meter is a demand-meter in which the indication of maximum demand is subject to a characteristic time lag.

8020* Period of an Instrument. The period of an instrument, sometimes called the "periodic time," is the time taken for the pointer to make one complete oscillation (two consecutive swings). A swing is a complete movement in either direction.

8030 Instrument Transformer. An instrument transformer is a transformer suitable for use with measuring instruments; that is, one in which the conditions of phase and of current or potential in the primary circuit, are represented with acceptable accuracy in the secondary circuit. An instrument transformer may be either an instrument current transformer or an instrument potential (voltage) transformer.

8031* Secondary Burden. The secondary burden of a current transformer is an expression in ohms and henrys of the resistance and inductance of the external circuit connected to the secondary of that transformer.

8032 Voltage Ratio of Instrument Transformer. The voltage ratio of an instrument potential transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary terminal voltage, under specified secondary burden.

8033 Current Ratio of Instrument Transformer. The current ratio of an instrument current transformer is the ratio of r.m.s. primary current to r.m.s. secondary current, under specified secondary burden.

8034 Marked Ratio of Instrument Transformer. The marked ratio of an instrument transformer is the ratio which the apparatus is designed to give under average conditions of use. When a precise ratio is required, it is necessary to specify the voltage or current, frequency, load and secondary burden.

OPERATION.

8101 Permissible Temperature in Shunts.—(*a*) *General*: The limiting observable temperature of shunts measured by Method I shall not exceed 120°C.

(b) *Exceptions*: The above rule shall not apply to shunts having no soldered joint and made of material which is not per-

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(8020) In strongly damped instruments, the period is influenced by the amplitude of the movement.

(8031) Considerable uncertainty of meaning has been occasioned by the use of the terms, load, secondary load, and secondary connected load for this quantity, and such use is discouraged.

manently changed in resistance if continuously subjected to a higher temperature.

8110 Grounding of Meters and Instruments. The covers of meters and instruments, which are used with current and potential transformers, shall be connected to the grounded sides of the secondary circuits of such transformers in all cases where the indications of the instrument are liable to be influenced by electrostatic action.

8111 Instrument Current Transformers on Open Secondary Circuit. Under conditions of open secondary circuit, current transformers shall be capable of carrying continuously rated primary current without damage to the primary insulation and without interruption of service.

8112 Instrument Current Transformers on Closed Secondary Circuit. Under conditions of closed secondary circuit, current transformers shall withstand 40 times rated current applied for 1 second, without injury.

RATING

8200 General. The rating of a meter is a designation assigned by the manufacturer to indicate its operating limitations. The full scale marking of an instrument does not necessarily correspond to its rating, but if the rating differs from the full scale marking, the rating shall be marked on the instrument.

8201 Standard Ambient Temperature.—For purposes of rating meters and shunts, the standard ambient temperature shall be 40°C. See §§**8301** and **2211**.

8202 Rating Limitation of the Circuits of Meters and Instruments. No circuit of a meter or instrument shall be given a rating higher than that corresponding to the maximum current or voltage to which it may be continuously subjected.

8203* Temperature Rise of Meter and Instrument Windings. The permissible temperature rises in meters and instruments shall be based upon the temperatures specified in §**1005** and the standard ambient temperature of 40° C.

8204 Temperature Rise in Shunts. Shunts shall be rated in accordance with their observable temperature rise by Method 1, assuming the ultimate temperatures specified in §**8101** and an ambient temperature specified in §**8201**.

TESTS.

8300 Measurement of Temperature Rise of Shunts. Observable temperature shall be measured in such a manner as not to cause local change of temperature.

8301 Standard Temperature of Reference for Meter and Instrument Characteristics. The standard temperature of reference for meter and instrument characteristics shall be 20° C. See §§**8201, 2211**.

(8203) Heating is frequently an immaterial consideration in determining the rating of meters and instruments. Losses, impairment of accuracy and other factors often determine the rating.

8302 Damping. The pointer being at zero before any load is applied, damping shall be measured by suddenly applying and maintaining a load which will give a steady deflection of one-half full angular scale, and observing the following quantities:

(*a*) The number of swings taken by the pointer in coming to rest.

(*b*) The time, in seconds, required for the pointer to come to rest.

(*c*) The overshooting, in per cent of the angular displacement due to the disturbance.

Dielectric Strength of Instrument Transformers.

8310 Test Voltage Instrument Potential Transformers. The test voltage for instrument potential transformers shall be twice the normal voltage of the circuit to which it is connected plus 1000 volts.

8311 Test Voltage of Instrument Current Transformers. The test voltage of instrument current transformers shall be 2¼ times the rated voltage plus 2000 volts.

8312 Test Voltage for Meters and Instruments. (The Institute is not at present in a position to make recommendations.)

SPECIFICATION OF CHARACTERISTICS.

8500 Errors of Indicating Instruments. In specifying the accuracy of an indicating instrument, the error at any point on the scale shall be expressed as a percentage of the full scale reading.

8501 Torque. The torque of meters and instruments shall be expressed in millimeter-grams.

8502 Damping. The damping of an instrument shall be expressed in terms of the quantities enumerated in §8302, all three of which are essential to a complete description.

8503* Marking of Switchboard Shunts. The marking of switchboard shunts shall include the rating in amperes, the drop in volts at that rating, and the serial number of any instrument in connection with which the shunt may be calibrated. When shunts are designed to be used with devices taking sufficient current to be an appreciable proportion of the whole, this fact shall be indicated.

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(8503) For example, if with 100 amperes rated load in the main circuit, a measuring device takes 10 amperes, leaving 100 less 10 amperes in the shunt with a drop of 0.050 volts, the shunt shall be marked: Volts 0.050. Amperes 100 less 10.

CHAPTER IX.

STANDARDS FOR WIRES AND CABLES

DEFINITIONS.

9000* **Wire.**—A wire is a slender rod or filament of drawn metal.

9001* **Conductor.**—A conductor is a wire or combination of wires not insulated from one another, suitable for carrying a single electric current.

9002* **Stranded Conductor.**—A stranded conductor is a conductor composed of a group of wires, or of any combination of groups of wires.

9003 **Strand.**—A strand is one of the wires, or groups of wires, of any stranded conductor.

9004* **Cable.**—A cable is either a stranded conductor (single-conductor cable), or a combination of conductors insulated from one another (multiple-conductor cable).

9005* **Stranded Wire.**—A stranded wire is a group of small wires, used as a single wire.

(9000) The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire; while primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated, the term "wire" will be understood to include the insulation.

(9001) The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents. Rolled conductors (such as bus-bars) are, of course, conductors, but are not considered under the terminology here given.

(9002) The wires in a stranded conductor are usually twisted or braided together.

(9004) The first kind of cable is a single conductor, while the second kind is a group of several conductors. The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead-covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one, and in practise, it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord", both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead, or with steel wires or bands.

(9005) A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands, and is used as a single wire, it is called a "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable". If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord", defined below.

9006* **Cord.**—A cord is a small cable, very flexible and substantially insulated to withstand wear.

9007 **Concentric Strand.**—A concentric strand is a strand composed of a central core surrounded by one or more layers of helically-laid wires or groups of wires.

9008 **Concentric-Lay Cable.**—A concentric-lay cable is a single-conductor cable composed of a central core surrounded by one or more layers of helically-laid wires.

9009* **Rope-Lay Cable.**—A rope-lay cable is a single-conductor cable composed of a central core surrounded by one or more layers of helically-laid groups of wires.

9010* **N-Conductor Cable.**—An N-conductor cable is a combination of N conductors insulated from one another.

9011* **N-Conductor Concentric Cable.**—An N-conductor concentric cable is a cable composed of an insulated central conductor with (N–1) tubular stranded conductors laid over it concentrically and separated by layers of insulation.

9012* **Duplex Cable.**—A duplex cable is a cable composed of two insulated stranded conductors twisted together.

9013 **Twin Cable.**—A twin cable is a cable composed of two insulated stranded conductors laid parallel, having a common covering.

9014 **Twin Wire.**—A twin wire is a cable composed of two small insulated conductors laid parallel, having a common covering.

9015* **Triplex Cable.**—A triplex cable is a cable composed of three insulated single-conductor cables twisted together.

9016* **Twisted Pair.**—A twisted pair is a cable composed of two small insulated conductors, twisted together, without a common covering.

9017* **Sector Cable.**—A sector cable is a multiple-conductor cable in which the cross-section of each conductor is substantially a sector, an ellipse, or a figure intermediate between them.

9018 **Round Conductor.**—A round conductor is either a solid or stranded conductor of which the cross-section is substantially circular.

(9006) There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Rubber is used as the insulating material for many classes of cords.

(9009) This kind of cable differs from the preceding in that the main strands are themselves stranded.

(9010) It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable" etc. In referring to the general case, one may speak of a "multiple-conductor cable" (as in §9004 above.)

(9011) This kind of cable usually has only two or three conductors. Such cables are used particularly for alternating currents. The remark on the expression "N-conductor" given for the preceding definition also applies here.

(9012) They may or may not have a common insulating covering.

(9015) They may or may not have a common insulating covering.

(9016) The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord."

(9017) Sector cables are used in order to obtain decreased overall diameter and thus permit the use of larger conductors in a cable of given diameter.

9019* **Split Conductor.**—A split conductor is a conductor which is divided into two or more parts, separated from one another by insulation which is thin compared with the insulation around the conductor.

9030 **Factor of Assurance.**—The factor of assurance of wire or cable insulation is the ratio of the voltage at which it is tested to that at which it is used.

9031 **Insulation Resistance.**—The insulation resistance of an insulated conductor is the electrical resistance offered by its insulation, to an impressed voltage tending to produce a leakage of current through the same.

9032* **Circular Mil.**—A circular mil is a unit of area equal to $\frac{\pi}{4}$ (=0.7854...) of a square mil. The cross-sectional area of a circle in circular mils is therefore equal to the square of its diameter in mils. A circular inch is equal to a million circular mils.

9033* **Lay.**—The lay of any helical element of a cable is the axial length of a turn of the helix of that element.

9034 **Direction of Lay.**—The direction of lay is the lateral direction in which the strands of a cable run over the top of the cable as they recede from an observer looking along the axis of the cable.

ANNEALED COPPER STANDARD

9050* **Standard Annealed Copper.**—(*a*) *General:* The following shall be taken as normal values for standard annealed copper.

(*b*) *Resistance:* At a temperature of 20° C., the resistance of a wire of standard annealed copper one meter in length and of a uniform section of 1 square millimeter is 1/58 ohm = 0.017241 . . . .ohm.

(*c*) *Density.* At a temperature of 20°C., the density of standard annealed copper is 8.89 grams per cubic centimeter.

(*d*) *Temperature Coefficient of Resistance:* At a temperature of 20°C., the "constant mass" temperature coefficient of resistance of standard annealed copper, measured between two potential points

(9019) The term split conductor usually designates a conductor in two parts or splits, which may be either concentric or external to one another.

(9032) A mil is the one-thousandth part of an inch. There are 1974 circular mils in a square milimeter.

(9033) Among the helical elements of a cable may be each strand in a concentric-lay cable, or each insulated conductor in a multiple conductor cable.

(9050) See I. E. C. Publication No. 28, "International Standard of Resistance for Copper", March, 1914.

Paragraphs (b) and (e) define what are sometimes called "Volume Resistivity" and "Mass Resistivity", respectively. This may be expressed in other units as follows:

Volume Resistivity =1.7241 microhms–cm. (microhms in a centimeter cube) at 20° C.

Mass Resistivity = 875.20 ohms (mile, pound) at 20° C.

For detailed specifications of commercial copper see the Standard Specifications of the American Society for Testing Materials.

rigidly fixed to the wire, is $0.00393 = 1/254.45\ldots$ per degree centigrade.

(e) *Resistance of Standard Annealed Copper at 20° C:* As a consequence, it follows from (a) and (b) that, at a temperature of 20° C. the resistance of a wire of standard annealed copper of uniform section, one meter in length and weighing one gram, is $(1/58) \times 8.89 = 0.15328\ldots$ ohm.

OPERATION

Temperature Limits.

9100* Maximum Temperatures.—The temperature of the insulation of a wire or cable at the surface of the conductor shall not be allowed to exceed the following values.

Let t = maximum safe temperature
E = r. m. s. operating electromotive force in kilovolts between conductors

Impregnated paper, $t = 85 - E$
Varnished cambric, $t = 75 - E$
Rubber insulation, $t = 60 - \frac{E}{4}$

DESIGNATION

9200 Designation of Wires by Diameter or Gage Number.—The sizes of wires shall be stated by their diameters in mils, the American Wire Gage (Brown and Sharpe) sizes being taken as standard. For brevity, in cases where the most careful specification is not required, the sizes of wires may be stated by the gage number in the American Wire Gage.

9201 Designation of Cables by Cross-Sectional Area.—The sizes of stranded conductors shall be stated by their cross-sectional area in circular mils or circular inches, except in the case of flexible stranded conductors, for which see §9402. The cross-sectional area of a

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(9100) For example: At a working pressure of 3.3 kv., the maximum safe limiting temperature at the surface of the conductor, or conductors, in a cable would be as follows:

For	impregnated paper	81.7°C.
"	varnished cambric	71.7°C.
"	rubber insulation	59.2°C.

The life of the insulation of a cable depends in a great measure upon the actual temperature attained by the insulation. The result of operating at temperatures in excess of the safe limit is to shorten the life of the insulating material. When the safe limits are exceeded, deterioration is rapid and permanent, the damage increasing with the length of time that the excessive temperature is maintained and with the amount of excess temperature until finally the insulation breaks down.

Some of the older types of cable for voltages above 7500 have a dielectric loss that is so high that it may add considerably to the heating that would otherwise result. In such cases the dielectric loss is a material factor in determining the safe load to be carried by the cable, and the safe operating temperature will be determined by the temperature at which cumulative heating occurs under the conditions of service, if this occurs at a lower temperature than that at which the insulation deteriorates.

cable shall be considered to be the sum of the cross-sectional areas of its component wires, when measured perpendicular to their axes. The sizes of stranded conductors smaller than 250,000 circular mils (*i.e.*, No. 0000 A.W.G. or smaller) may be stated by means of the gage number of a solid wire having the same cross-sectional area.

9202* **Conductivity.**—The conductivity of the metal of wires shall be expressed in terms of the conductivity of the Annealed Copper Standard, as defined in §**9050**.

9203* **Copper-Wire Tables.**—The copper-wire Tables published by the Bureau of Standards in Circular No. 31 are adopted. Table VI therein gives the values of diameters and cross-sections of A. W. G. sizes to four significant figures. These Tables are based upon the Annealed Copper Standard described in §**9050**.

TESTS.

General

9300 **Cable Lengths Tested.**—Electrical tests of insulation on wires and cables shall be made on the entire lengths to be shipped.

9301 **Immersion in Water.**—(*a*) *General:* The outer surface of the insulation of complete insulated wires and cables shall be grounded while being electrically tested. If the insulation is not provided with a conducting covering, and if the covering is not liable to injury by water, the ground shall be obtained by immersing the insulated wire or cable in water for at least twelve hours and testing at the end of that period while immersed. If the outer covering is susceptible to injury by immersion, the insulated conductor shall be tested before the application of such covering.

Dry core paper insulated lead covered cables, such as telephone and telegraph cables, for use in water, shall be tested after at least twelve hours immersion.

(b) *Multiple-Conductor Cable:* In the case of multiple-conductor cables, without waterproof overall jacket of insulation, no immersion test should be made on finished cables, but only on the individual conductors before assembling.

Tests of Dielectric Strength

9310 **Object of Tests.**—High voltage tests are intended to detect weak spots in the insulation and to determine whether its

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(9202) For any given wire, let

C = conductivity, in per cent of Annealed Copper Standard
L = length, meters
R = resistance, ohms
W = weight, grams
t = temperature, degrees centigrade

Then the conductivity may be derived from the following formula:

$$C = \frac{15.328}{\frac{W R}{L^2} + 0.000597\,(20-t)}$$

(9203) For detailed specifications of commercial copper, see the Standard Specifications of the American Society for Testing Materials.

dielectric strength is sufficient for enabling it to withstand the voltage to which it is likely to be subjected in service, with a suitable factor of assurance.

9311 Nature of Tests.—High-voltage tests shall be made at the factory, by applying an alternating voltage between the conductor and sheath or water. The initially applied voltage must not be greater than the working voltage, and the rate of increase shall be approximately uniform and not over 100 per cent in 10 seconds.

9312* Magnitude and Duration of the Test Voltage.—(a) *General:* Wires and cables shall be tested at the place of manufacture for five consecutive minutes, except as provided in § **9312** (b) and (f).

(*b*) *Rubber Insulation, National Electrical Code:* Rubber covered wires and cables for working pressures up to 600 volts alternating, insulated in accordance with the requirements of the National Electrical Code, shall be tested in accordance with that Code.

(*c*) 30% to 40% *Hevea Rubber Insulation for Pressures up to* 600 *Volts, a-c.*: Wires and cables for working pressures up to 600 volts alternating, insulated with 30% to 40% Hevea rubber compound, unless the insulation thickness is less than specified in §**9405**, shall be tested in accordance with Table 901.

TABLE 901

High Voltage Tests for Rubber Insulated Wires and Cables.

(30% to 40% Hevea Rubber Insulation for working pressures up to 600 Volts a-c.)

Size A. W. G. or Cir. Mils.	Size Sq. mm.	Test pressure kilovolts
14–8	2.081 – 8.366	3.0
7–0000	10.55 –107.2	3.5
250,000 & larger	127 and larger	4.0

(*d*) *Thirty to Forty per cent Hevea Rubber Insulation for Pressures over* 600 *Volts A-C:* Wires and cables insulated with 30% Hevea rubber compound for working pressures over 600 volts alternating, shall be tested with one kilovolt per 64th inch of thickness (2.53 kv, per mm.) up to 10/64th inch, (3.96 mm.) Above 10/64ths inch, (3.96 mm.), the test pressure shall be 10 kilovolts plus 1.5 kilovolts per 64th inch (3.79 kv. per mm.) additional up to 30/64ths inch (11.89 mm.). Where the insulation thickness is 16/64ths inch (6.34 mm.) or over, this rule shall apply only to conductors over 26,000 cir. mils (13.2 sq. mm.) area.

(e) *Varnished Cambric and Impregnated Paper Insulation:* Varnished cambric and impregnated paper insulated wires or cables shall be tested in accordance with Table 902.

(9312-c) Hevea rubber is rubber from the Hevea Brasiliensis tree. Compounds containing 30 to 40% of Hevea rubber have electrical and mechanical properties superior to compounds insulated in accordance with the requirements of the National Electric Code.

(9312-e) Different engineers specify different thickness of insulation for the same working voltages. Therefore, at the present time the test kv. corresponding to working kv. given in Table 902, are based on the *minimum* thickness of insulation specified by engineers and operating companies.

TABLE 902

High-Voltage Tests for Varnished Cambric or Impregnated Paper Insulated Cables.

(Minimum Values.)

Operating kv.	Test kv.	Operating kv.	Test kv.
Below 0.5	2.5*	5	14
0.5	3	7.5	19.5
1	4	10	25
2	6.5	over 10	2½ times operating pressure
3	9		
4	11.5		

*The minimum thickness of insulation shall be 1/16 in. (1.6 mm.)

For intermediate working voltages, the test voltage shall be interpolated.

(*f*) *Telephone, Telegraph and Annunciator Wires and Cables*: Section **9312** shall not apply to wires and cables for telephone, telegraph, annunciator and similar devices.

9313 Frequency of Test Voltage.—The frequency of the test voltage shall not exceed 100 cycles per second, and should approximate as closely as possible to a sine wave. The source of energy should be of ample capacity.

9314 Dielectric Strength Tests.—Ultimate dielectric strength tests, when required, shall be made on samples not more than 6 meters (20 ft.) long. The maximum allowable temperature, at which the test is made, for the particular type of insulation and the particular working pressure, shall be not greater than the temperature limits given in **§9100.**

9315 Multiple-Conductor Cables.—If a multiple conductor cable is designed for the same operating voltage between conductors and sheath or water as between conductors, each conductor shall be tested against the other conductors connected together and to the sheath or water. If the cable is designed for an operating voltage between conductors and ground different from that between conductors, the test between conductors and the sheath or water shall be made separately and shall be based on the normal operating voltage between conductors and sheath or water as prescribed in **§9312.**

Insulation Resistance

9320* Expression of Insulation Resistance.—Insulation resistance shall be expressed in megohms. Linear insulation resistance, or the insulation resistance of unit length, shall be expressed in terms of the megohm-kilometer, or the megohm-mile, or the megohm-thousand-feet, and shall be corrected to a temperature of 15.5° C., using a

(9320) In the case of dry core paper insulated cables, the temperature coefficient of insulation resistance cannot be closely determined on account of variations in design and manufacture. Therefore no temperature corrections shall be applied to insulation resistance tests. Tests should be made at a temperature of 15.5 ° C. or higher.

temperature coefficient determined experimentally for the insulation under consideration.

9321 **Megohms Constant.**—The megohms constant of an insulated conductor shall be the factor "K" in the following equation:

$$R = K \log_{10} \frac{D}{d}$$

where R = insulation resistance, in megohms, for a specified unit length.

D = outside diameter of insulation.

d = diameter of conductor.

Unless otherwise stated, K will be assumed to correspond to the mile unit of length.

9322 **Measurement of Insulation Resistance.**—The apparent insulation resistance should be measured after the high-voltage test, measuring the leakage current after a one-minute electrification, with a continuous e.m.f. of from 100 to 500 volts, the conductor being maintained negative to the sheath or water.

9323 **Insulation Resistance of Multiple-Conductor Cables.**—The insulation resistance of each conductor of a multiple-conductor cable shall be the insulation resistance measured from each conductor to all the other conductors in multiple with the sheath or water.

Capacitance or Electrostatic Capacity

9330* **Expression of Capacitance.**—Capacitance shall be expressed in microfarads. Linear capacitance, or the capacitance of unit length, shall be expressed in microfarads per unit length (kilometer, or mile, or one thousand feet), and shall be corrected to a temperature of 15.5° C., using a temperature coefficient determined experimentally for the insulation under consideration.

9331 **Microfarads Constant.**—The microfarads constant of an insulated conductor shall be the factor "K" in the following equation:

$$C = \frac{K}{\operatorname{Log}_{10} \frac{D}{d}}$$

where C = capacitance in microfarads per unit length.

D = outside diameter of insulation.

d = diameter of conductor.

Unless otherwise stated, K will be assumed to refer to the mile unit of length.

(9330) In the case of dry core paper insulated cables, the temperature coefficient of capacitance cannot be determined closely on account of variations in design and manufacture. Therefore no temperature corrections shall be applied to capacitance tests. Tests should be made at a temperature of 15.5° C. or higher.

TABLE 903

Proposed Standard Cables

(This table is offered for consideration but will not be recommended for final adoption until ratified by other societies interested.)

Strands			Total nominal cross section circular mils	Total diam., inches
	Individual wires			
Number & Size. See Note 4.	Nominal diam. mils	Nominal cir. mils.		
127 No. 8	128.5	16,510	2,097,000	1.671
127 No. 9	114.4	13,090	1,662,000	1.487
91 No. 8	128.5	16,510	1,502,000	1.414
91 No. 9	114.4	13,090	1,191,000	1.258
61 No. 8	128.5	16,510	1,007,000	1.157
61–121 mils	121.0	14,641	893,100	1.089
61 No. 9	114.4	13,090	798,500	1.030
61–107 mils	107.0	11,449	698,400	.963
61 No. 10	101.9	10,380	633,200	.917
37–116 mils	116.0	13,456	497,900	.812
37 No. 10	101.9	10,380	384,100	.713
37–97 mils	97.0	9,409	348,100	.679
37 No. 11	90.74	8,234	304,700	.635
19 No. 9	114.4	13,090	248,700	.572
19–107 mils	107.0	11,449	217,500	.535
19 No. 11	90.74	8,234	156,400	.454
19 No. 12	80.81	6,530	124,100	.404
19 No. 13	71.96	5,178	98,380	.360
19 No. 14	64.08	4,107	78,030	.320
7 No. 10	101.9	10,380	72,660	.306
7 No. 11	90.74	8,234	57,640	.272
7 No. 12	80.81	6,530	45,710	.242
7 No. 14	64.08	4,107	28,750	.192
7 No. 16	50.82	2,583	18,080	.152
7 No. 18	40.30	1,624	11,370	.121
7 No. 20	31.96	1,022	7,154	.096
7 No. 22	25.35	642.4	4,497	.076
7 No. 24	20.10	404.0	2,828	.060

Note 1. Nominal diameters and circular mils of the individual wires are taken from Table VI, circular No. 31 of the Bureau of Standards.

Note 2. The variation of the mean diameter of any wires shall not exceed 1 per cent above or below the nominal diameter.

Note 3. The variation of the total cross-section of the cable shall not exceed 1 per cent above or below the nominal cross-section.

Note 4. Sizes are expressed as A. W. G. numbers except where diameters are given in mils.

9332 Measurement of Capacitance.—The capacitance of cable shall be measured with alternating current by comparison with a standard condenser. It is preferable that the measurement be made either at a frequency approximating that of operation or at a frequency giving results approximating those corresponding to the operating frequency or frequencies.

9333 Capacitance of Paired Cables.—The capacitance of paired cables shall be measured between the two conductors of any pair, the other wires being connected to the sheath or ground.

9334 Capacitance of Multiple-Conductor Cables (not paired).—The capacitance of multiple conductor (not paired) cables shall be measured between conductors, and also between each conductor and the other conductors connected to the sheath or ground.

CONSTRUCTION

Stranding

9400* Proposed Standard Cables.—Insulated cables not requiring special flexibility shall be made of the number and size strands specified in Table 903.

9401 Cables not Requiring Special Flexibility.—Cables not requiring special flexibility and not made in accordance with §**9400** shall be stranded in accordance with Table 904.

TABLE 904

Standard Stranding of Concentric-Lay Cables

SIZE (See note 1.)	Sq. mm.	Number of Wires (See note 2) A Bare, insulated or weatherproof cables for aerial use.	B Insulated cables for other than aerial use.
2.0 Cir. Inches	1013	91	127
1.5 "	760	61	91
1.0 "	507	61	61
0.6 "	304	37	61
0.5 "	253	37	37
0.4 "	203	19	37
0000 A. W. G.	107	19 or 7 (See note 3.)	19
00 "	67.4	7	19
2 "	33.6	7	7
7 and smaller	10.5	..	7

Note 1. For intermediate sizes, use stranding for next larger size.

Note 2. Conductors of 0000 A. W. G. and smaller are often made solid and this table of stranding should not be interpreted as excluding this practice.

Note 3. Class A cable, sizes 0000 and 000 A. W. G., is usually made of 7 strands when bare and 19 strands when insulated or weatherproof.

(9400) The basis of this rule is the use of strands of American Wire Gage sizes. To meet existing operating conditions, four sizes of strands other than American Wire Gage sizes have been deemed necessary and their diameters are shown in mils.

9402* Flexible Cables.—Conductors of special flexibility should ordinarily be made with wires of regular A.W.G. sizes, and rated by the number and size of wires. The stranding of flexible cables is given in Table 905.

TABLE 905

Stranding of Flexible Cables

Nearest A.W.G. size (see Note 1)	Circular mils (see Note 2)	Diam. of cable, mils	No. of wires	Size of each wire		Construction (see Note 3)
				A.W.G.	Diam. mils	
..	2039000	1885.	703	15.5	53.9	37 × 19
..	1816000	1779.	"	16.0	50.8	"
..	1617000	1679.	"	16.5	48.0	"
..	1440000	1584.	"	17.0	45.3	"
..	1284000	1496.	"	17.5	42.7	"
..	1103000	1372.	427	16.0	50.8	61 × 7
..	874600	1222.	"	17.0	45.3	"
..	693600	1088.	"	18.0	40.3	"
..	550000	969.	"	19.0	35.9	"
..	436200	863.	"	20.0	32.0	"
..	345900	768.	"	21.0	28.5	"
..	274300	684.	"	22.0	25.3	"
..	264600	671.	259	20.0	32.0	37 × 7
0000	209800	598.	"	21.0	28.5	"
000	171300	538.	133	19.0	35.9	19 × 7
00	135900	479.	"	20.0	32.0	"
0	107700	427.	"	21.0	28.5	"
1	82780	332.	91	20.5	30.2	Concentric
2	65650	295.	"	21.5	26.9	"
3	52060	263.	"	22.5	23.9	"
4	39190	228.	61	22.0	25.3	"
5	31080	203.	"	23.0	22.6	"
6	24650	181.	"	24.0	20.1	"
8	17410	152.	"	25.5	16.9	"
10	10560	118.	37	25.5	16.9	"
12	6640	94.	"	27.5	13.4	"
14	4176	74.	"	29.5	10.6	"
Smaller	....	....	To equal Required Size	30.0	....	Bunched

NOTE 1. The A.W.G. cross-sectional areas except for 61 strands, are approximated within 2 per cent. In the case of 61 strand cables the approximation is 6 per cent.

NOTE 2. Circular mils are based on theoretical diameters of A.W.G. sizes, which vary above or below values given in table by less than 0.1 mil.

NOTE 3. "61 × 7" in the rating of a rope-lay cable signifies 61 strands of 7 wires each.

(9402) Where necessary to closely approximate a regular size cable, the strands may be made of half-size wires from No. 15 to No. 30 A. W. G.

9403* **Correction for Lay.**—Two per cent shall be taken as the standard increment of resistance and of mass, due to stranding. In cases where the lay is definitely known, the increment should be calculated and not assumed.

Thickness of Insulation

9405 **Thickness of Insulation for Rubber Insulated Wires and Cables.**—Unless special conditions warrant departures from this rule, the thickness of insulation for rubber compounds containing from 30 to 40 per cent of Hevea rubber, shall be in accordance with Table 906.

TABLE 906

Thickness of Insulation

30 to 40 per cent Hevea Rubber Compound

Recommended Walls of Insulation, 64ths. Inch.

Size A. W. G. or Cir. Mils	Sq. mm.	Working pressure, volts alternating										
		600 or less	1500	2500	3500	5000	6000	7000	8000	9000	10000	11000
14–8	2.08–8.37	3	6	8	10	12	14	16	18	20	22	24
7–2	10.6–33.6	4	7	9	10	12	14	16	18	20	22	24
1–0000	42.4–107	5	8	10	10	12	14	16	18	20	22	24
250,000–500,000	127–253	6	9	10	11	12	14	16	18	20	22	24
550,000–1,000,000	279–507	7	10	10	12	12	14	16	18	20	22	24
1,250,000–2,000,000	633–1013	8	10	10	12	14	16	18	18	20	22	24

NOTES. In multiple conductor cables, the thickness of insulation on each conductor shall be based on the highest r. m. s. voltage between the conductor and the outside of this insulation. The above table is based upon alternating voltages of commercial frequencies. For voltages over 600, the insulation thickness for direct-current cable has not been established. For intermediate sizes the insulation thickness should be the same as for the next larger sizes.

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(9403) The resistance and mass of a stranded conductor are greater than in a solid conductor of the same cross sectional area, depending on the lay (*i.e.*, the pitch of the twist of the wires).

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CHAPTER X.

STANDARDS FOR STORAGE BATTERIES

Rules to be included in the Chapter have been prepared, and await final consideration before publication.

CHAPTER XI.

STANDARDS FOR ILLUMINATION

This chapter consists of extracts from the Report of the Committee on Nomenclature and Standards of the Illuminating Engineering Society for the year 1918. It is here included by permission.

General

11000 Radiant flux, ϕ, is the rate of flow of radiation evaluated with reference to energy, and is expressed in ergs per second or in watts.

11001 Luminous flux, F, is the rate of flow of radiation evaluated with reference to visual sensation, and is expressed in lumens.

11002 Visibility, K_λ, of radiation of a particular wave-length is the ratio of the luminous flux at that wave-length to the corresponding radiant flux.

Defining equation:

$$K_\lambda = \frac{F_\lambda}{\Phi_\lambda}$$

11003* The Mechanical equivalent of light is the ratio of radiant flux to luminous flux for the wave-length of maximum visibility, and is expressed in ergs per second per lumen, or in watts per lumen. It is the reciprocal of the maximum visibility.

11004 Luminosity of a particular wave-length is the product of the visibility of that wave-length and the corresponding ordinate of the spectral curve of radiant flux, and is represented by the ordinate of the spectral curve of luminous flux. This curve is called the spectral luminosity curve and is different with different sources.

11005 The **Luminous efficiency** of any source is the ratio of the luminous flux to the radiant flux from the source and is expressed in lumens per watt.

11006 Luminous intensity I, of a source of light in a given direction is the solid angular density of the luminous flux emitted by the source in the direction considered, when the flux involved acts as far as computation and measurements are concerned, as if it came from a

(11003). This term has been used in a variety of senses. As here defined it refers only to the minimum mechanical equivalent of light. The reciprocal of this quantity is sometimes called the luminous equivalent of radiation.

point. Or, it is the flux per unit solid angle from that source in the direction considered. The flux from any source of dimensions which are negligibly small by comparison with the distance at which it is observed, may be treated as if it were emitted from a point.

Defining equation:

$$I = \frac{dF}{d\omega}$$

or, if the intensity is uniform,

$$I = \frac{F}{\omega}$$

where ω is the solid angle.

11007 **Illumination,** E, of a surface at any point is the luminous flux density on the surface at that point, or the flux per unit of intercepting area.

Defining equation:

$$E = \frac{dF}{dS}$$

or, when uniform,

$$E = \frac{F}{S}$$

where S is the area of the intercepting surface.

11008* **Candle** is the unit of luminous intensity maintained by the national laboratories of France, Great Britain and the United States.

11009 **Candlepower,** cp., is luminous intensity expressed in candles.

11010* **Lumen,** *l.*, is the unit of luminous flux equal to the flux emitted in a unit solid angle (steradian) by a point source of unit candlepower.

11011 **Lux** is a unit of illumination equal to one lumen per square meter. Using the centimeter as the unit of length, the unit of illumination is one lumen per square centimeter, for which Blondel has proposed the name **phot.** One millilumen per square centimeter (**milliphot**) is more useful as a practical unit. One **foot-candle** is one lumen per square foot, and is equal to 1.0764 milliphots. The milliphot is recommended for scientific records.

11012 **Brightness** of an element of a luminous surface may be expressed in either of two ways: (*a*) in terms of intensity, I, (*b*) in terms of flux, F.

(*a*) Brightness in terms of the luminous intensity I (or candlepower) per unit of projected area of the surface (candlepower brightness) corresponds to the

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(11008). This unit, which is used also by many other countries, has frequently been referred to as the international candle.

(11010) A uniform source of one candlepower emits 4π lumens.

$$\text{defining equation, } b_I = \frac{d\,I}{d\,S \cos\,\theta}$$

where θ is the angle between the normal to the surface and the line of sight.

(*b*) Brightness in terms of the flux, F, proceeding from a unit area of the surface, on the assumption that the surface is a perfect diffuser; *i. e.*, that it obeys the cosine law of emission or reflection, (lumen brightness) corresponds to the

$$\text{defining equation, } b_F = \frac{d\,F}{d\,S}$$

(perfect diffusion assumed).

The units in which brightness is measured according to (*a*) and (*b*) differ only in numerical value.

11013 Lambert, L, is the unit of brightness in the lumen system. The lambert is the brightness of a perfectly diffusing surface emitting or reflecting one lumen per square centimeter. For most purposes the **millilambert,** 0.001 lambert, is the preferable practical unit.

To say that the brightness of a surface as viewed from a given point is n lamberts, signifies that its brightness is the same as that of a perfectly diffusing surface emitting or reflecting n lumens per square centimeter.

In practice no surface obeys exactly the cosine law of emission or reflection; hence the brightness of a surface generally is not uniform but varies somewhat with the angle at which it is viewed.

A perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts.

Brightness expressed in candles per square centimeter may be reduced to lamberts by multiplying by $\pi = 3.14$.

Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by $\pi/6.45 = 0.487$.

Surfaces and Media Modifying Luminous Flux

11020 Diffusing surfaces and media are those which break up the incident flux and distribute it more or less in accordance with the cosine law, as for example, white plaster and opal glass.

11021 Redirecting surfaces and media are those which change the direction of the luminous flux in a definite manner; as for example, a mirror or a lens.

11022 Scattering surfaces and media are those which redirect the luminous flux and break it up into a multiplicity of separate pencisl; as for example, ripple glass, reflecting or transmitting.

11023* Reflection factor, of a body ρ, is the ratio of the flux reflected by the body to the flux incident upon it. The reflection from a

(11023) (11024) (11025) These terms are introduced to replace the more commonly used terms, Coefficient of reflection, Coefficient of absorption, Coefficient of transmission, which latter terms refer to the specific properties of materials rather than to the behavior of bodies under specified conditions, such as angle of incidence, etc.

body may be regular, diffuse or mixed. In regular reflection the flux is reflected at an angle of reflection equal to the angle of incidence. In diffuse reflection the flux is reflected in all directions. In perfectly diffuse reflection, the distribution of the reflected flux is in accordance with Lambert's cosine law. In most practical cases, there is a superposition of regular and diffuse reflection.

11024* **Absorption factor,** of a body a, is the ratio of the flux absorbed by the body to the flux incident upon it.

11025* **Transmission factor,** of a body τ, is the ratio of the flux transmitted by the body to the flux incident upon it.

$$\rho + a + \tau = 1$$

Illumination

11030 **Unidirectional** illumination on a surface is that produced by a single light source of relatively small dimensions. It is characterized by the fact that a small opaque object placed near the illuminated surface casts a sharp shadow.

11031 **Multidirectional** illumination on a surface is that produced by several separated light sources of relatively small area. It is characterized by the fact that a small opaque object placed near the illuminated surface casts several shadows.

11032 **Diffused** illumination is that produced either by primary or secondary light sources having dimensions relatively large with respect to the distance from the point illuminated, and scattering light in all directions. It is characterized by relative lack of shadow. Diffused illumination may be derived principally from a single direction as in the light from a skylit window or from all directions as in the open air. Perfectly diffused illumination on a surface is shadowless.

In any practical case of illumination on a surface there is usually a mixture of the above types.

11033 **Coefficient of utilization** of an illumination installation on a given plane is the total flux received by that plane divided by the total flux from the lamps illuminating it. When not otherwise specified, the plane of reference is assumed to be a horizontal plane 30 inches (76 cm.) from the floor.

11034 **Variation factor** of an illumination installation is the ratio of either the maximum or minimum illumination on a given plane to the average illumination on that plane.

11035 **Variation range** of illumination on a given plane is the ratio of the maximum illumination to the minimum illumination on that plane.

11036 **Hemispherical ratio** for a given lighting unit is the ratio of the luminous flux in the upper hemisphere to that in the lower hemisphere.

11037 **Brightness ratio** is the ratio of the brightness of any two surfaces. When the two surfaces are opposed, the brightness ratio is commonly called the "brightness contrast."

Illuminants

11040 The **output** of all illuminants should be expressed in lumens.

11041 **Illuminants should be rated** upon a lumen basis rather than a candlepower basis.

11042 **Lamp efficiency** is the ratio of the luminous flux output to the power input.

11043 **The lamp efficiency** or **specific output of electric lamps** should be stated in terms of lumens per watt and that of illuminants depending upon combustion should be stated in lumens per British thermal unit per hour.

11044 **The power consumption of auxiliary devices** which are necessarily employed in circuit with a lamp should be included in the input of the lamp. For example, the watts lost in the ballast resistance of an arc lamp are properly chargeable to the lamp.

11045 **The specific consumption** of an electric lamp is its watt consumption per lumen. "Watts per candle" is a term used commercially in connection with electric incandescent lamps, and denotes watts per mean horizontal candle.

11046 **Life Tests.**—Electric incandescent lamps of a given type may be assumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life test results, in order to be compared, must be either conducted under, or reduced to, comparable conditions of operation.

11047 **In comparing different luminous sources** not only should their candlepower be compared, but also their relative form, brightness, distribution of illumination and character of light.

Lamp Accessories

11048 A **reflector** is an appliance the chief use of which is to redirect the luminous flux of a lamp in a desired direction or directions.

11049 A **shade** is an appliance the chief use of which is to diminish or to interrupt the flux of a lamp in certain directions where such flux is not desirable. The function of a shade is commonly combined with that of a reflector.

11050 A **globe** is an enclosing appliance of clear or diffusing material the chief use of which is either to protect the lamp or to diffuse its light.

Photometry

11060 **Performance curve** is a curve representing the behavior of a lamp in any particular (candlepower, consumption, etc.) at different periods during its life.

11061 **Characteristic curve** is a curve expressing a relation between two variable properties of a luminous source, as candlepower and volts, candlepower and rate of fuel consumption, etc.

11062 **Mean horizontal candlepower** of a lamp is the average candle power in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner, or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

11063 **Mean spherical candlepower** of a lamp is the average candlepower of a lamp in all directions in space. It is equal to the total luminous flux of the lamp in lumens divided by 4π.

11064 **Mean hemispherical candlepower** of a lamp (upper or lower) is the average candlepower of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp in that hemisphere divided by 2π.

11065 **Mean zonal candlepower** of a lamp is the average candlepower of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone divided by the solid angle of the zone.

11066* **Spherical reduction factor** of a lamp is the ratio of the mean spherical to the mean horizontal candlepower of the lamp.

TABLE 1100

11067 **Photometric Units and Abbreviations.**

Photometric quantity	Name of unit	Symbols and defining equations	Abbreviation for name of unit
1. Luminous flux	Lumen	$F \,.\, \psi$	l.
2. Luminous intensity	Candle	$I = \frac{dF}{d\omega},\ \Gamma = \frac{d\psi}{d\omega}$	cp.
3. Illumination	Phot, foot-candle, lux	$E = \frac{dF}{dS} = \frac{I}{r^2}\cos\theta.$	ph. fc.
4. Exposure	Phot-second Micro phot-second	$E\,t$	phs. μ phs.
5. Brightness	Apparent candle per sq. cm. Apparent candle per sq. in.	$b_i = \frac{dI}{dS\cos\theta}$	—
	Lambert	$b_l = \frac{dF}{dS}$	L. mL.
6. Reflection factor	—	ρ	—
7. Absorption factor	—	α	—

(11066). In the case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.

* Perfect diffusion assumed.

8. Transmission factor τ
9. Mean spherical candlepower scp.
10. Mean lower hemispherical candlepower lcp.
11. Mean upper hemispherical candlepower ucp.
12. Mean zonal candlepower zcp.
13. Mean horizontal candlepower mhc.
14. 1 lumen is emitted by 0.07958 spherical candlepower.
15. 1 spherical candlepower emits 12.57 lumens.
16. 1 lux = 1 lumen incident per square meter = 0.0001 phot = 0.1 milliphot.
17. 1 phot = 1 lumen incident per square centimeter = 10,000 lux = 1,000 milliphots = 1,000,000 microphots.
18. 1 milliphot = 0.001 phot = 0.929 foot-candle.
19. 1 foot-candle = 1 lumen incident per square foot = 1.076 milliphots = 10.76 lux.
20. 1 lambert = 1 lumen emitted per square centimeter of a perfectly diffusing surface.
21. 1 millilambert = 0.001 lambert.
22.*1 lumen, emitted, per square foot = 1.076 millilamberts.
23.*1 millilambert = 0.929 lumen, emitted, per square foot.
24. 1 lambert = 0.3183 candle per square centimeter = 2.054 candles per square inch.
25. 1 candle per square centimeter = 3.1416 lamberts.
26. 1 candle per square inch = 0.487 lambert = 487 millilamberts.

CHAPTER XII.

STANDARDS FOR TELEPHONY AND TELEGRAPHY

Many of the following definitions are tentative and not yet fully established. Criticisms and suggestions, addressed to the Secretary of the Standards Committee, will be welcomed. Some of the definitions are specific to telephony, and differ in detail from similar definitions appearing in other parts of the rules.

DEFINITIONS

Line Circuits

12000 **Ground-Return Circuit.**—A ground-return circuit is a circuit consisting of one or more metallic conductors in parallel, with the circuit completed through the earth.

12001 **Metallic Circuit.**—A metallic circuit is a circuit of which the earth forms no part.

12002 **Two-Wire Circuit.**—A two-wire circuit is a metallic circuit formed by two parallel conductors insulated from each other.

12003 **Superposed Circuit.**—A superposed circuit is an additional circuit obtained from a circuit normally required for another service, and in such a manner that the two services can be given simultaneously without mutual interference.

12004 **Phantom Circuit.**—A phantom circuit is a superposed circuit, each side of which consists of the two conductors of a two-wire circuit in parallel.

12005 **Side Circuit.**—A side circuit is a two-wire circuit forming one side of a phantom circuit.

12006 **Non-Phantomed Circuit.**—A non-phantomed circuit is a two-wire circuit, which is not arranged for use as the side of a phantom circuit.

12007 **Simplexed Circuit.**—A simplexed circuit is a two-wire telephone circuit, arranged for the superposition of a single ground-return signalling circuit operating over the wires in parallel.

12008 **Composited Circuit.**—A composited circuit is a two-wire telephone circuit, arranged for the superposition on each of its component metallic conductors, of a single independent ground-return signalling circuit.

12009 **Quadded or Phantomed Cable.**—A quadded or phantomed cable is a cable adapted for the use of phantom circuits.

12010 **Simplex Circuit.**—A simplex circuit in telegraphy is one arranged for operation in one direction at one time.

12011 **Duplex Circuit.**—A duplex circuit in telegraphy is one arranged for simultaneous operation in opposite directions.

12012 **Diplex Circuit.**—A diplex circuit in telegraphy is one arranged for the simultaneous transmission of two messages in the same direction.

12013 **Quadruplex Circuit.**—A quadruplex circuit in telegraphy is one arranged for the simultaneous transmission of two messages in each direction.

12014 **Multiplex Circuit.**—A multiplex circuit in telegraphy is one arranged for the simultaneous transmission of one or more messages in both directions. Both duplex and quadruplex are examples of multiplex whereas diplex is not.

12015 **Linear Electrical Constants.**—The linear electrical constants of a line are the electrical constants per unit length of the line, *e. g.* linear resistance, linear inductance, etc.

12016 **Smooth Line.**—A smooth line is a line whose electric elements are all continuously and uniformly distributed throughout its length.

12017* **Periodic Line.**—A periodic line is a line consisting of successive similar sections in each of which one or more electric elements are not distributed uniformly. As examples of periodic lines are (1) loaded lines and (2) artificial lines consisting of successive similar sections of lumped constants.

12018 **Equivalent Smooth Line.**—An equivalent smooth line of a periodic line is a smooth line having the same electrical behavior as the periodic line, at a given single frequency, when measured at terminals or at corresponding section junctions.

12019 **Equivalent Periodic Line.**—An equivalent periodic line of a smooth line is a periodic line having the same electrical behavior, for an assumed single frequency, as the smooth line, when measured at terminals or at corresponding section junctions. The terms conjugate smooth line and conjugate periodic line are also sometimes used.

12020 **Composite Line.**—A composite line is a line consisting of a plurality of successive sections having different linear electrical constants, as in the case where an underground cable section is joined to an overhead open-wire section.

12021 **Loaded Line.**—A loaded line is one in which the normal reactance of the circuit has been altered for the purpose of increasing its transmission efficiency.

12022 **Series Loaded Line.**—A series loaded line is one in which the normal reactance has been altered by reactance serially applied.

12023 **Shunt Loaded Line.**—A shunt loaded line is one in which the normal reactance of the circuit has been altered by reactance applied in shunt across the circuit.

(12017) The term periodic in this definition refers to the line constants and not to time relations.

12024 Continuous Loading.—A continuous loading is a series loading in which the added inductance is uniformly distributed along the conductors.

12025* Coil Loading.—A coil loading is one in which the normal inductance is altered by the insertion of lumped inductance in the circuit at intervals.

Circuit Constants and Characteristics

12050 Damping of a Circuit.—The damping at a given point in a circuit from which the source of energy has been withdrawn, is the progressive diminution in the effective value of electromotive force and current at that point resulting from the withdrawal of electrical energy.

12051* Damping Constant.—The damping constant of a circuit is a measure of the ratio of the dissipative to the reactive component of its admittance or impedance.

12052* Mutual Impedance.—The mutual impedance for single frequency alternating currents, between a pair of terminals and a second pair of terminals of a network, under any given condition, is the negative ratio of the electromotive force produced between either pair of terminals on open circuit to the current flowing between the other pair of terminals.

12053* Self-Impedance.—The self-impedance between a pair of terminals of a network, under any given condition, is the ratio of the electromotive force applied across the terminals to the entering current.

12054* Characteristic Impedance.—The characteristic impedance of a line is the ratio of the applied electromotive force to the resulting steady-state current upon a line of infinite length and uniform structure, or of periodic recurrent structure.

(12025) This lumped inductance may be applied either in series or in shunt.

As commonly understood, coil loading is a series loading, in which the lumped inductance is applied at uniformly spaced recurring intervals.

(12051) Applied to the admittance of a condenser or other simple circuit having capacity reactance, the damping constant for a harmonic electromotive force of given frequency is the ratio of the conductance G, of the condenser or simple circuit at that frequency to twice the capacitance, C, of the condenser at the same frequency, $(G/2\ C)$.

Applied to the reactance of a coil or other simple circuit having inductive reactance, the damping constant for a harmonic current of a given frequency is the ratio of the resistance, R, of the coil or circuit at that frequency to twice the inductance, L, at the same frequency $(R/2\ L)$.

(12052) A receiving-end impedance is an example of a mutual impedance.

Single frequency voltages and currents are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

(12053) Single frequency voltages and currents are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

(12054) In practise, the terms (1) line impedance, (2) surge impedance, (3) iterative impedance, (4) sending-end impedance, (5) initial sending-end impedance, (6) final sending-end impedance, (7) natural impedance and (8) free impedance, have apparently been more or less indefinitely and indiscriminately used as synonyms with what is here defined as "characteristic impedance."

Single frequency voltages and currents are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

12055* **Sending-End Impedance.**—The sending-end impedance of a line is the ratio of the applied electromotive force to the resulting steady-state current at the point where the electromotive force is applied.

12056* **Propagation Constant.**—The propagation constant of a uniform line, or section of a line of periodic recurrent structure, is the natural logarithm of the ratio of the steady-state currents at various points separated by unit length in a uniform line of infinite length, or at successive corresponding points in a line of recurrent structure of infinite length. The ratio is determined by dividing the value of the current at the point nearer the transmitting end by the value of the current at the point more remote.

12057 **Attenuation Constant.**—The attenuation constant for a single frequency is the real part of the propagation constant taken at that frequency.

12058 **Wave-Length Constant.**—The wave-length constant is the imaginary part of the propagation constant.

12059 **Standard Cable.**—A standard cable is an ideal uniform line in terms of which the attenuation of a line or network may be specified. It is characterized by the following constants: Linear resistance, 88 ohms per loop mile (54.7 ohms per loop km.). Linear capacitance between wires 0.054 microfarad per loop mile (0.03355 microfarad per loop km.). Linear inductance and linear leakance, 0.

Equivalent Circuits

12102* **Equivalent Circuit.**—An equivalent circuit is a simple network of series and shunt impedances, which, at a given frequency, is the approximate electrical equivalent of a complex network.

12103* **"*T*" Equivalent Circuit.**—A "*T*" equivalent circuit is a triple-star or "*Y*" connection of three impedances externally equivalent to a complex network. See Fig. 12-1 for symbol.

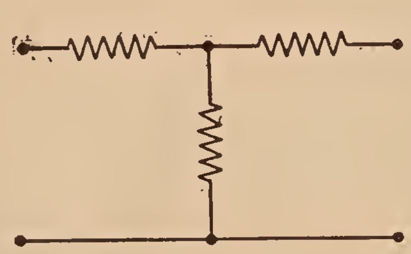

FIG. 12-1

12104* **"*I*" Equivalent Circuit.**—An "*I*" equivalent circuit is a connection of five impedances in the form shown in Fig. 12-2, which is externally equivalent to a complex network. It differs from the "*T*" equivalent circuit in that the impedances are arranged symmetrically

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(12055) See note under "Characteristic Impedance," In case the line is of infinite length of uniform structure or of periodic recurrent structure, the sending-end impedance and the characteristic impedance are the same.

Single frequency voltages and currents are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

(12056) Single frequency voltages and currents are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

(12102 to 12106 Incl.) As ordinarily considered, the simple networks as defined, are the electrical equivalents of complex networks only with respect to definite pairs of terminals.

on the two sides of the circuit, which is often desirable in connection with practical problems, as indicating that the circuit is balanced with respect to ground.

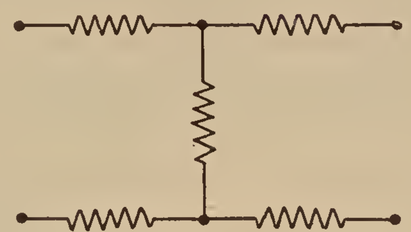

FIG. 12-2

12105* **"Π" Equivalent Circuit.**—A "Π" equivalent circuit is a delta connection of three impedances externally equivalent to a complex network. It is also called a "*U*" equivalent circuit. See Fig. 12-3 for symbol.

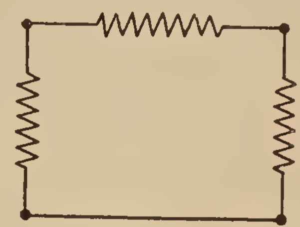

FIG. 12-3

12106* **"*O*" Equivalent Circuit.**—An "*O*" equivalent circuit is a connection of four impedances in the form shown in Fig. 12-4, externally equivalent to a complex network. It differs from the Π equivalent circuit in that the impedances are arranged symmetrically on the two sides of the circuit, which is often desirable in connection with practical problems, as indicating that the circuit is balanced with respect to ground.

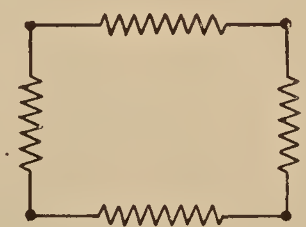

FIG. 12-4

Telephony

12200 **Manual Telephone System.**—A manual telephone system is one in which the calling party gives his order to an operator who completes the call directly by hand, either with or without the assistance of one or more additional operators.

12201 **Automatic or Full Mechanical Telephone System.**—An automatic or full mechanical telephone system is one in which the calling party is enabled to complete a call by remote-control switches without the aid of an operator.

12202 **Semi-Automatic or Semi-Mechanical Telephone System.**— A semi-automatic or semi-mechanical telephone system is one in which the calling party gives his order to an operator who completes the call through remote-control switches.

12203 **Telephone Exchange.**—A telephone exchange consists of one or more central offices with associated plant, by means of which telephone service is rendered in a specified local community.

12204 **Telephone Exchange Area or District.**—A telephone exchange area or district is the area or district served by a telephone exchange.

12205 **Central Office.**—A central office is a switching center for interconnecting lines terminating therein.

12206 **Toll Central Office.**—A toll central office is one in which toll and long distance lines terminate.

12207 **Local Central Office.**—A local central office is one in which subscriber's lines terminate.

12208 **Private Branch Exchange (Generally Abbreviated "P. B. X.").**— A private branch exchange is a telephone system generally installed on the premises of a subscriber, including a switchboard and extension sets, and connected to a central office, affording intercommunication between the extension sets and also between these sets and the central office.

12209 **Private Exchange.**—A private exchange is one which serves one business organization or individual, and is not connected to a central office.

12210 **Private Automatic Exchange.**—A private automatic exchange is an automatic exchange which serves one business organization or individual, and is not connected to a central office.

12211 **Subscriber Set (Often Abbreviated to "Subset").**—A subscriber set is an assembly of apparatus for sending and receiving telephone calls.

12212 **Subscriber Station (Often Abbreviated to "Substation").**— A subscriber station is an installed subscriber set connected to a central office for the purpose of sending and receiving telephone calls.

12213 **Pay Station.**—A pay station is a subscriber station available for the use of the public on the payment of a fee. The fee may be either deposited in a coin box or paid to an attendant.

12214 **Toll Station.**—A toll station is a pay station located outside of a local service area and affording toll and long distance service only.

12215 **Subscriber line or Subscriber Loop.**—A subscriber line or subscriber loop is the wire connection between a subscriber station and the central office.

12216 **Subscriber Line Circuit.**—A subscriber line circuit is a subscriber line with its associated individual central office apparatus.

12217 **Individual Line.**—An individual line is a subscriber line which connects one subscriber station to a central office, though it may have one or more extension sets.

12218 **Party Line.**—A party line is a subscriber line which connects two or more subscriber stations to a central office.

12219 **Tip Side or Tip Wire, Ring side or Ring Wire.**—The tip side or wire, or the ring side or wire, is that conductor of a circuit which is associated with the corresponding member of a jack.

12220 **Negative Side or Negative Wire, Positive side or Positive Wire.**—The negative side or wire, or the positive side or wire, is that conductor of a circuit which is normally connected to the corresponding pole of a battery.

12221 **Main Distributing Frame.**—A main distributing frame is a structure for terminating the permanent inside and outside wires of a central office and for effecting flexible junctions between them.

12222 **Intermediate Distributing Frame.**—An intermediate distributing frame is a structure for terminating permanent inside wires of a central office and for effecting flexible junctions between them.

12223 **Switchboard.**—A switchboard is an assemblage of apparatus in a coordinate structure for switching talking and signaling circuits.

12224 **Switchboard Section.**—A switchboard section is an element or unit one or more of which constitutes a complete manual switchboard.

12225 **Operating Room.**—An operating room is a room which contains a manual switchboard and associated apparatus.

12226 **Combination Current.**—A combination current consists of two or more currents of different characterisitics in the same circuit. As ordinarily used the term refers to currents whose characteristics are steadily maintained, as for example, a combination of direct current and an alternating current.

12227 **Manual Ringing.**—Manual ringing is ringing which is affected by and continues with the operation of a key.

12228 **Machine Ringing.**—Machine ringing is intermittent and is caused to act periodically by the apparatus itself.

12229 **Superimposed Ringing Current.**—A superimposed ringing current is a combination current for ringing, consisting of a direct and an alternating current.

12230 **Pulsating Ringing Current.**—A pulsating ringing current is a current for ringing in which the succeeding impulses are separated by intervals approximately equal to those of the impulses themselves.

12231 **Harmonic Selective Signaling.**—Harmonic selective signaling employs devices tuned mechanically or electrically to the frequency of the ringing current, so that each device will not operate when receiving current intended to operate another device.

12232 **Multiple Harmonic Signaling.**—Multiple harmonic signaling employs frequencies which are integral multiples of the lowest frequency.

12233 **Non-Multiple Harmonic Signaling.**—Non-Multiple harmonic signaling employs frequencies which are not integral multiples of the lowest frequency.

12234 **"To Call".**—"To call" is to originate a telephone call.

12235 **"To Dial".**—"To dial" a number is to use a dial type of calling device in order to control automatic switches.

12236 **"To Set Up".**—"To set up" a number is to use a key type or multiple lever type of calling device in order to control automatic switches.

12237 **Calling Device.**—A calling device is an apparatus by means of which automatic switches are controlled for the purpose of establishing a connection.

12238 **Calling Party.**—A calling party is a person who originates a telephone call.

12239 **Called Party.**—A called party is the person who answers when a station is called.

12240 **Reverting Call.**—A reverting call is one between two stations on the same subscriber line.

12241 **Telephone Traffic.**—Telephone traffic is the aggregate volume of communication handled in a given time.

12242 **"Busy".**—"Busy" is the condition of a line or an apparatus when it is in use.

12243 **Free.**—Free is the condition of a line or an apparatus when it is not in use. Free is the opposite of busy.

12244 **"To Make Busy".**—"To make busy" is to cause a line or an apparatus to appear to be busy.

12245 **"To Release" or to "Disconnect.**—"To release" or "to disconnect" is to terminate a telephone connection by disengaging the apparatus.

12246 **"To Clear".**— To clear" is to restore a line or an apparatus to the free condition.

12247 **Trunk.**—A trunk is the wire connection between switching devices or central offices.

12248 **Trunk Circuit.**—A trunk circuit is a trunk with its associated individual apparatus.

12249 **Trunked Call.**—A trunked call is one which employs an inter-office trunk or a trunk between two switchboard positions.

12250 **Relay.**—A relay is a device by means of which contacts in one circuit are operated by a change in conditions in the same circuit or in one or more associated circuits. (See Rule **4016** Standardization Rules, A. I. E. E., 1918).

12251 **Polar Relay.**—A polar relay is a relay which operates in response to a change in the direction of the current in the controlling circuit.

12252 **Quick Operating Relay.**—A quick operating relay is one which operates its contacts within a specified brief time limit.

12253 **Quick Release Relay.**—A quick release relay is one which releases its contacts within a specified brief time limit.

12254 **Quick Acting Relay.**—A quick acting relay is one which has the properties of both a quick operating and a quick release relay.

12255 **Slow Operating Relay.**—A slow operating relay is one which will not operate until after a specified delay.

12256 **Slow Release Relay.**—A slow release relay is one which when operated will not release until after a specified delay.

12257 **Slow Acting Relay.**—A slow acting relay is one which has the properties of both a slow operating and a slow release relay.

12258 **Line Relay.**—A line relay is one whose coil is normally in the line circuit.

12259 **Cut-Off Relay.**—A cut-off relay is one which when operated disconnects from a line apparatus normally connected to it.

12260 **Relay Coil Section.**—A relay coil section is one of two or more windings of a coil on one and the same core. The several sections may be concentric or placed side by side on the core.

12261 **Tension Spring.**—A tension spring is one which functions to exert mechanical pressure but does not carry an electrical current.

12262 **Contact Spring.**—A contact spring is one which takes an electrical part in switching a circuit.

12263 **Main Contact Spring.**—A main contact spring is one which may switch a circuit between two or more other contact springs.

12264 **Armature Spring.**—An armature spring is the first of a group to be moved by the armature. It may or may not be a main contact spring.

12265 **Plunger Spring.**—Aplunger spring is the first of a group to be moved by the plunger.

12266 **Impulse Springs.**—Impulse springs are those which act to make or break a circuit for the purpose of sending impulses.

12267 **Make-Before-Break Contact Springs (Abbreviation "M. B. B.").**—make-before-break contact springs are those in which the main spring touches the front contact before it breaks away from the back contact. Also called a continuity preserving contact.

12268 **Back Contact Spring.**—A back contact spring is one against which the main contact spring rests when in the normal position.

12269 **Front Contact Spring.**—A front contact spring is one against which the main contact spring rests when in the operated position.

12270 **Automatic Signaling.**—Automatic signaling is affected without the aid of an operator.

12271 **Automatic Switch.**—An automatic switch is a remote control device for controlling talking or signaling circuits.

12272 **Finder Switch.**—A finder switch is a switch connected to one of a smaller number of circuits and which finds automatically a circuit out of a larger number of circuits from whence the signal comes.

12273 **Line Switch.**—A line switch is a switch connected to one of a larger number of circuits from which a signal comes and which finds automatically a circuit out of a smaller number of circuits.

12274 **Selector Switch.**—A selector switch is a switch whose duty is to select a particular group of trunks and one trunk of the group selected. In particular cases, one of these functions may be omitted.

12275 **Connector Switch or Final Selector.**—A connector switch or final selector is a switch whose duty is to establish a connection with the called line. It is usually operated by the last digit or digits of the call number.

12276 **Switch Frame.**—A switch frame is a structure for mounting an assembly of switching apparatus which may be integral therewith.

12277 **Section of Switches.**—A section of switches, considered from a trunking standpoint, is a group of adjacent switches whose banks are multipled together.

12278 **Switchroom.** A switchroom is a room which contains an assemblage of automatic switches and associated apparatus.

12279 **Bank Wires.**—Bank wires are those wires which multiple adjacent switch banks to each other.

12280 **Bank Cable.**—A bank cable is one which connects a switch bank to a terminal rack.

12281 **Multiple Cable.**—A multiple cable is one which multiples together two or more sections of switch banks by connecting together their terminals.

12282 **Impulse.**—An impulse is any sudden change of brief duration produced in the current of a circuit.

12283 **Make Impulse.**—A make impulse is an impulse due to a temporary flow of current.

12284 **Break Impulse.**—A break impulse is an impulse due to a temporary interruption of current.

12285 **Impulse Frequency.**—The impulse frequency is the number of impulses occurring per second. The reciprocal of this is the impulse period.

12286 **Impulse Period.**—The impulse period is the period of time included between the corresponding points in periodically recording impulses. It thus corresponds to the period of alternating current.

12287 **Impulse Ratio.**—Impulse ratio is the ratio of duration of an impulse to the impulse period.

12288 **Impulse Circuit.**—An impulse circuit is one through which impulses are transmitted.

12289 **Telephone Impulse Repeater.**—A telephone impulse repeater is a device for repeating impulses from one line circuit into another and for performing other duties.

12290 **Supervisory Signal.**—A supervisory signal is a device for attracting attention of an attendant to a duty in connection with switching apparatus or its accessories. This includes cord supervisory lamps on a manual switchboard and the supervisory lamps in an automatic exchange which indicates that a switch has been occupied but has not completed its function.

12291 **Tell-Tale Signal.**—A tell-tale signal is a device for locating the failure of some apparatus; for example, the blowing of a fuse, the continued drawing of heavy current by apparatus intended to receive only momentary current, etc.

12292 **Alarm Signal.**—An alarm signal is a sound producing device for attracting attention to either a supervisory or a tell-tale signal.

12293 **Amplifier.**—See §**13040.**

12294 **Telephone Repeater.**—A telephone repeater is a device for amplifying a voice current from one line circuit into another line circuit

12300 **Telephone Receiver.**—A telephone receiver is an electrically operated device designed to produce sound waves or vibrations which correspond to the electromagnetic waves or vibrations actuating it.

12301 **Microphone.**—A contact device designed to have its electrical resistance directly and materially altered by slight differences in mechanical pressure.

12302 **Telephone Transmitter.**—A telephone transmitter is a sound-wave-operated or vibration-operated device designed to produce electromagnetic waves or vibrations which correspond to the sound waves or vibrations actuating it.

12303* **Coefficient of Coupling of a Transformer.**—The coefficient of coupling of a transformer at a given frequency is the ratio of the mutual impedance between the primary and secondary of the transformer, to the square root of the product of the self-impedances of the primary and of the secondary.

12304 **Repeating Coil.**—A term used in telephone practice meaning the same as transformer, and ordinarily a transformer of unity ratio.

12305* **Retardation Coil.**—A retardation coil is a reactor (reactance coil) used in a circuit for the purpose of selectively reacting on currents which vary at different rates.

Telegraphy

12500 **Relay.**—A relay is a device by means of which contacts in one circuit are operated by a change in conditions in the same circuit or in one or more associated circuits.

12501 **Polar Relay.**—A polar relay is a relay which operates in response to a change in the direction of the current in the controlling circuit.

12502 **Non-Polar Relay, or Neutral Relay.**—A non-polar relay is a relay which operates in response to a change in the strength of the current in the controlling circuit, irrespective of the direction of the current.

12503 **Neutral Relay.**—See non-polar relay.

12504 **Selector.**—A selector is a device which performs certain functions such as causing an electric lamp to light, or an electric bell to sound, in response to a definite signal or group of successive signals received over a controlling circuit.

(12303) Single frequency voltages and currents are here supposed to be represented by complex numbers. Their ratio is therefore a complex number.

(12305) In telephone and telegraph usage, the terms "impedance coil," "inductancecoil," "choke coil" and "reactance coil" are sometimes used in place of the term "retardation coil."

12505 **Direct-Point Repeater.**—A direct-point repeater is a repeater in which the receiving relay controlled by the signals received over a line repeats these signals into another line or lines without the interposition of any other repeating or transmitting apparatus.

12506 **Concentrator.**—A concentrator is a traffic distributing device by means of which a number of telegraph or telephone lines, and connections to operating instruments are brought together at one point to facilitate their interconnection at such times as signals or messages are to be transmitted from one to the other.

12507 **Transmitter.**—A transmitter is a device for effecting electrical changes in a controlled circuit. The term transmitter is commonly applied principally to devices which in response to a controlling means effects in a main line telegraph circuit electrical changes necessary to send signals over the line.

12508 **Synchronous System.**—A synchronous system of telegraphy is one in which the proper transmission and reception of signals is dependent upon the synchronous operation of similar commutators or other devices located at the sending and receiving stations of a circuit.

12509 **Differential Duplex.**—A differential duplex is a duplex system in which at each station one of two portions of the receiving instrument is connected in series with the line wire and the other in series with an artificial line of such electrical characteristics that the effects upon the receiver of currents passing through the main and artificial lines, as a result of outgoing signals, are neutralized.

12510 **Bridge Duplex.**—A bridge duplex is a duplex system in which the receiving instruments at each station is connected across two impedances, one in series with the line wire and the other in series with the artificial line in such manner that no electrical change in the receiver circuit is effected by outgoing signals.

12511 **Half-Set Repeater.**—A half-set repeater is a repeater used for connecting together a simplex circuit and a duplexed circuit converting them into the equivalent of a single simplex circuit.

12512 **Intermediate Current Supply.**— An intermediate current supply is an ungrounded source of current connected in series with a line wire at a station other than a terminal on a ground return telegraph circuit.

12513 **Phantoplex Circuit.**—A phantoplex circuit is a superposed circuit operated by alternating current over a simplex, duplex or quadruplex circuit operated from direct current sources.

12514 **Spark Condenser.**—A spark condenser is a condenser, with or without associated non-inductive resistance, connected with a pair of instrument contact points for the purpose of diminishing sparking at these points.

12515 **Current Margin.**—In a non-polar simplex system, the difference between the current flowing through a receiving instrument when operated to that flowing when not operated.

12516 Margin Ratio.—In a non-polar simplex system, the ratio of the current flowing through a receiving instrument when operated to that flowing when not operated.

12517 Percentage Margin.—In a non-polar simplex, the current margin expressed as a percentage of the current flowing through the relay when operated.

12518 Main Circuit.—A main circuit is a major electrical circuit of a telegraph system and includes both transmitting and receiving devices.

12519 Local Circuit.—A local circuit is a circuit, within the limits of the station, usually controlled by a receiving instrument in a main circuit or controlling a transmitter effecting changes in a main line circuit

CHAPTER XIII.

STANDARDS FOR RADIO COMMUNICATION

General

This chapter has been mainly abstracted from the report of the Standardization Committee of the Institute of Radio Engineers, and is here included by permission, until further revised. For full particulars, see the I. R. E. Standardization Committee report.

13000 Acoustic Resonance Device.—One which utilizes, in its operation, resonance to the audio frequency of the received signals.

13001 Antenna.—A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.

13002 Atmospheric Absorption.—That portion of the total loss of radiated energy due to atmospheric conductivity.

13003 Audio Frequencies.—Frequencies corresponding to the normally audible vibrations. These are assumed to lie below 10,000 cycles per second.

13004 Capacitive Coupler.—An apparatus which, by electric fields joins portions of two radio-frequency circuits, and which is used to transfer electrical energy between these circuits through the action of electric forces.

13005 Coefficient of Coupling (Inductive).—The ratio of the effective mutual inductance of two circuits to the square root of the product of the effective self-inductances of each of these circuits.

13006 Direct Coupler.—A coupler which magnetically joins two circuits having a common conductive portion.

13007 Counterpoise.—A system of electrical conductors forming one portion of a radiating oscillator, the other portion of which is the antenna. In land stations a counterpoise forms a capacitive connection to ground.

13008 Damped Alternating Current.—A damped alternating current is an alternating current whose amplitude progressively diminishes.

13009 Damping Factor.—The damping factor of an exponentially damped alternating current is the product of the logarithmic decrement and the frequency.

Let I_0 = initial amplitude

I_t = amplitude at the time t

ϵ = base of Napierian logarithms

a = damping factor

Then: $I_t = I_0\, \epsilon^{-at}$

13010 Detector.—That portion of the receiving apparatus which, connected to a circuit carrying currents of radio frequency, and in conjunction with a self-contained or separate indicator,

translates the radio-frequency energy into a form suitable for operation of the indicator. This translation may be effected either by the conversion of the radio frequency energy, or by means of the control of local energy by the energy received.

13015 **Electromagnetic Wave.**—A periodic electromagnetic disturbance progressing through space.

13016 **Forced Alternating Current.**—A current, the frequency and damping of which are equal to the frequency and damping of the exciting electromotive force.

13017 **Free Alternating Current.**—The current following any electromagnetic disturbance in a circuit having capacitance, inductance, and *less* than the critical resistance.

13018 **Critical Resistance of a Circuit.**—That resistance which determines the limiting condition at which the oscillatory discharge of a circuit passes into an aperiodic discharge.

13019 **Group Frequency.**—The number per second of periodic changes in amplitude or frequency of an alternating current.

NOTE 1. Where there is more than one periodically recurrent change of amplitude or frequency, there is more than one group frequency present.

NOTE 2. The term "group frequency" replaces the term "spark frequency."

13020 **Inductive Coupler.**—An apparatus which, by magnetic forces, joins portions of two radio-frequency circuits and is used to transfer electrical energy between these circuits, through the action of these magnetic forces.

13025 **Logarithmic Decrement.**—The logarithmic decrement of an exponentially damped alternating current is the logarithm of the ratio of successive current amplitudes in the same direction.

NOTE: Logarithmic decrements are standard for a complete period or cycle.

Let: I_n and I_{n+1} be successive current amplitudes in the same direction.

d = logarithmic decrement

Then: $$d = \log_\epsilon \frac{I_n}{I_{n+1}}$$

13026 **Radio Frequencies.**—The frequencies higher than those corresponding to the normally audible vibrations, which are generally taken as 10,000 cycles per second. See also Audio Frequencies.

NOTE: It is not implied that radiation cannot be secured at lower frequencies and the distinction from audio frequencies is merely one of definition based on convenience.

13027 **Resonance.**—Resonance of a circuit to a given exciting alternating e. m. f. is that condition due to variation of the inductance or capacity in which the resulting effective current (or voltage) in that circuit is a maximum.

13028 **Standard Resonance Curve.**—A standard resonance curve is a curve the ordinates of which are the ratios of the square of the current at any frequency to the square of the resonant current, and the abscissas are the ratios of the corresponding wave length to the resonant wave length; the abscissas and ordinates having the same scale.

13029 **Sustained Radiation.**—Sustained radiation consists of waves radiated from a conductor in which an alternating current flows.

13030 **Tuning.**—The process of securing the maximum indication by adjusting the time period of a driven element. (See Resonance.)

13035 **Wave-Meter.**—A wave-meter is a radio-frequency measuring instrument, calibrated to read wave lengths.

13036 **Decremeter.**—An instrument for measuring the logarithmic decrement of a circuit or of a train of electromagnetic waves.

13037 **Attenuation, Radio.**—The decrease with distance from the radiating source, of the amplitude of the electric and magnetic forces accompanying (and constituting) an electromagnetic wave.

13038 **Attenuation, Coefficient of (Radio).**—The coefficient which, when multiplied by the distance of transmission through a uniform medium, gives the natural logarithm of the ratio of the amplitude of the electric or magnetic forces at that distance, to the initial value of the corresponding quantities.

13039 **Coupler.**—An apparatus which is used to transfer radio-frequency energy from one circuit to another by associating portions of these circuits.

13040 **Amplifier.**—An amplifier is an instrument which modifies the effect of a local source of energy in substantial accordance with the wave-form of the received energy, and gives out a wave of greater amplitude than that which it receives.

13041 **Interference.**—See **§12045.**

13042 **Phase Angle Defect.**—The phase angle defect of a condenser is the departure from quadrature of the phase difference between potential and current at terminals. This is sometimes called the phase angle of a condenser: although strictly speaking the phase angle of a condenser is 90° less the phase angle defect, and is therefore exactly 90° when the phase angle defect is zero.

13043 **Impulse E. m. f.**—An e. m. f. the effective value of which becomes small compared with its maximum value in a time which is short compared with the duration of the current which it causes.

13044 **Directive Coefficient.**—The directive coefficient of a transmitting antenna at a given distance therefrom on the surface of the earth or sea, for a given wave length, is the ratio of average field intensity within an angle of stated degrees centered about the direction of maximum radiation, to the average field intensity in all directions.

13045 **Directional Selectivity.**—The directional selectivity of a receiving antenna at a given wave length is the ratio of the average e. m. f. induced in that antenna for waves of equal intensity coming from

directions comprised within an angle of stated degrees centered about the direction of best reception, to the average e. m. f. induced in the antenna for waves of equal intensity coming from all directions.

13046 **Radiation Efficiency.**—The radiation efficiency of an antenna at a given wave length is the ratio of radiation resistance to the antenna resistance.

13047 **Selectivity.**—The (overall) selectivity of a receiving system is the product of the several selectivities of that system.

13048 **Average Selectivity.**—The average selectivity of a receiving system is the *nth* root of the product of the *n* selectivities of that system.

13049* **Radio-Frequency Selectivity.**—The radio-frequency selectivity of a simple element* of a receiving system is the ratio of resonant response (in terms of effective voltage or current measured at the indicator) to the non-resonant response when the radio-frequency portions of the elements of that system are detuned by one per cent of the resonant frequency.

(13049) A simple element as referred to a combination of an inductance, a capacitance and optionally a resistance; or their mechanical equivalent.

CHAPTER XIV.

STANDARDS FOR PRIME MOVERS AND GENERATOR UNITS

General

14000 **Regulation of Steam Engines, Steam Turbines and Internal Combustion Engines.**—In steam engines, steam turbines and internal combustion engines, the percentage speed regulation is usually expressed as the percentage ratio of the maximum variation of speed, to the rated-load speed in passing slowly from rated-load to no-load (with constant conditions at the supply.)

14001 **Fluctuation of Steam Engines, Steam Turbines and Internal Combustion Engines.**—The percentage fluctuation of a steam engine, steam turbine or internal combustion engine, is the immediate percentage speed regulation corresponding to a sudden change from rated-load to no-load.

14002 **Regulation of Hydraulic Turbines.**—In a hydraulic turbine, or other water motor, the percentage speed regulation is expressed as the percentage ratio of the maximum variation is speed in passing slowly from rated-load to no-load (at constant head of water), to the rated-load speed.

14003 **Regulation of Generator Units.**—In a generator unit consisting of a generator combined with a prime mover, the speed or voltage regulation shall be based upon constant conditions of the prime mover; *i. e.*, constant steam-pressure, head, etc. It includes the inherent speed variations of the prime mover. For this reason, the regulation of a generator unit is to be distinguished from the regulation of either the prime mover, or of the generator combined with it, when taken separately.

14010* **Variation in Prime Movers.**—The variation in prime movers which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360 degrees. See §4088.

14011 **Pulsation in a Prime Mover, or in the Alternator Connected Thereto.**—The pulsation in a prime mover, or in the alternator

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(14010) If p is the number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct connected, and $p\,n$ times the variation of the prime mover if rigidly connected thereto in such a manner that the angular speed of the alternator is n times that of the prime mover.

connected thereto, is the ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

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CHAPTER XV.

STANDARDS FOR TRANSMISSION LINES AND DISTRIBUTION LINES

NOTE:—For flash-over tests of insulators, see foot-note to §2361.

General

15000 **Regulation of Transmission Lines, Feeders, etc.**—The regulation of transmission lines, feeders, etc., is the change in the voltage at the receiving end between rated non-inductive load and no-load, with constant impressed voltage upon the sending end. The percentage regulation is the percentage change in voltage to the normal rated voltage at the receiving end.

CHAPTER XVI.

MISCELLANEOUS STANDARDS

HEATING DEVICES

16000 **Value of A-C. Test Voltage for Household Devices.**—Heating devices taking not over 660 watts, intended solely for operation on supply circuits not exceeding 275 volts, shall be tested with 500 volts at operating temperature.

INTERNATIONAL ELECTROTECHNICAL COMMISSION RULES

INTERNATIONAL ELECTROTECHNICAL COMMISSION

I. E. C. RULES FOR ELECTRICAL MACHINERY

VOLUME I.

(*Adopted at the Plenary Meeting, held in London, October, 1919*)

These rules apply to rotating machines of which the terminal pressure does not exceed 5000 volts or of which the rated output does not exceed 750 KVA., or of which the stator cores do not exceed 50 cm. in length axially, and to all transformers which are not water-cooled.

PART I. GENERAL.

I. Scope of Rules.

1. *Rotating Machines.*—The rules of the I. E. C. contained in this publication apply to rotating machines, of which the terminal pressure does not exceed 5000 volts or of which the rated output does not exceed 750 kVA, or of which the stator cores do not exceed 50 cm. in length axially.

2. *Transformers.*—These rules also apply to all transformers which are not water cooled. (For water-cooled transformers, *see* Appendix II.)

3. *Altitude.*—In the absence of any information in regard to the height above sea level at which the machine is intended to work in ordinary service, this height is assumed not to exceed 1000 meters. If the machine is intended to work at an altitude above 1000 metres a correction to the temperature rise should be applied. The value for this correction has not yet been fixed by the I. E. C.

4. *Temperature.*—In the absence of any information to the contrary. it is assumed that the temperature of the cooling air shall not exceed 40°C,

II. Definitions.

5. *Rating.*—(*See* Appendix IV.)

6. *Use of the term "Machine."*—The term "machine" is used in these rules in its most general sense so as to avoid the constant repetition of the words "machines, transformers and other electromagnetic induction apparatus."

7. *Use of the term "Power."*—It is usual to speak of a machine by its *power*. It is necessary to note that the term "power" should be used in the following way:—

(*a*) For direct current generators, the electric power at the terminals expressed in watts (W) or kilowatts (kW).

(*b*) For alternators, the apparent power at the terminals, expressed in volt-amperes (VA) or kilovolt-amperes (kVA).

(*c*) For motors, the mechanical power available at the shaft, expressed in watts (W) or kilowatts (kW).

(*d*) For transformers, apparent output at the secondary terminals, expressed in volt-amperes (VA) or kilovolt-amperes (kVA).

III. I. E. C. Rating.

8. *Test Rating.*—The I. E. C. rating has been established as a *test,* rating which will enable an exact comparison to be made between machines of different makes.

9. *Classes of Rating.*—There are two classes of I. E. C. rating:—

(*a*) The I. E. C. continuous rating (*see* Clause 10).

(*b*) The I. E. C. short time rating or limited time rating (*see* Clause 12).

10. *Continuous Rating.*—The I. E. C. continuous rating is the load which can be carried on test, under the conditions of that rating, for an unlimited period without the limits of the I. E. C. rules, as regards temperature rise, being exceeded.

11. *Service thermally equivalent to the Continuous Rating.*—Any machine intended for continuous service on fluctuating load may be given for test purposes a thermally equivalent I. E. C. continuous rating, provided that the service for which it is intended shall not cause in any of its parts temperatures or temperature rises in excess of those allowed by the I. E. C. rules when the machine is tested under the conditions of its continuous rating.

General Note re Classes of Fluctuating Load Service inserted by the Editing Committee.—It is desirable to distinguish between two kinds of fluctuating load service:—

(*i*) *That in which the overload peaks can be sustained be a machine of ordinary construction, without modification, and without exceeding the limits of temperature rise allowed by these rules for the machine when tested under its I. E. C. continuous rating.*

(*ii*) *That in which the overload peaks involve special provisions in design or construction either for mechanical or for electrical reasons.*

To designate this second class of service it is customary in Great Britain and the United States of America to employ the term "duty cycle rating," and the word "cycle" in this case signifies a period of time sufficiently long to include all the variations of load which might influence either the electrical construction or the mechanical construction of the machine.

12. *Short Time Rating.*—The I. E. C. short time rating is the load which can be carried on test for the time specified in the rating, the test being started with the machine cold and carried out under all the conditions of the rating, without the limits fixed by these I. E. C. rules, as regards temperature rise, being exceeded.

13. *Service thermally equivalent to the Short Time Rating.*—Any machine intended for service on loads which vary considerably may be

given for test purposes a thermally equivalent I. E. C. short time rating provided that the service for which it is intended shall not occasion in any of its parts temperatures or temperature rises in excess of those allowed by these rules when the machine is tested under the conditions of its short time rating.

PART II. INFORMATION TO BE GIVEN WITH ENQUIRIES AND ORDERS FOR ELECTRICAL MACHINES.

IV. General Information.

NOTE.—The term *machine* is used in these rules in its most general sense so as to avoid the constant repetition of the words *machines, transformers* and other *electro-magnetic induction apparatus.*

14. *General Information.*—The inquiry or order for an electrical machine should give the following general information:—

(*a*) The service output.

(*b*) The class of service required.

In the absence of any indication to the contrary continuous service is understood.

(*c*) The maximum temperature of the cooling air in which the machine is intended to work when it exceeds 40°C.

In the absence of any definite information it is understood that the temperature of the cooling air will not exceed 40°C.

(*d*) The altitude of the place where the machine is intended to work if its exceeds 1000 metres. In regard to altitude, *see* Clause 3.

(*e*) Any special requirements, if necessary, with regard to windings, methods of connection, neutral points and special tapping points, etc.

(*f*) When the apparatus is intended to operate in parallel with other apparatus the fact should be stated.

(*g*) Any special requirements in regard to electrical and mechanical details such as protective devices, cooling arrangements, etc.

(Specific recommendations regarding these details will be made at a later date by the I. E. C.)

V. Supplementary Information.

15. *Supplementary Information.*—The above general information should be completed by the following supplementary information in regard to the particular machine forming the subject of the order:—

16. *Direct-current Generator.*

Output at the terminals, in watts (W) or kilowatts (kW).
Pressure between terminals, in volts.
Current, in amperes.
Speed, in revolutions per minute.
Method of excitation.

17. *Direct-current Motor.*

Output at the shaft, in watts (W) or in kilowatts (kW).
Pressure between terminals, in volts.
Current, approximate, in amperes.
Speed at rated output, approximate, in revolutions per minute.
Method of excitation.

18. *Alternating-current Transformer.*

Frequency, in periods per second.

Number of phases.

Output, in voltamperes (VA), or in kilovoltamperes (kVA).

Primary pressure between terminals, in volts.

Secondary pressure between terminals, in volts, at no-load and at rated output with statement as to the power factor of the circuit fed by the secondary. If the power factor is not specified it shall be taken as 0.8.

Secondary current, in amperes.

For transformers intended to work in parallel, the primary pressure, current, and power factor on short circuit test, shall also be stated.

For three-phase transformers the method of connection shall also be indicated in accordance with the vector diagrams (*see* Appendix I.).

Any special requirements as to the accessibility of neutral points and special tapping points shall be indicated.

NOTE.—Whatever may be the nature of the transformers (step-up or step-down) the primary terminals are those which are connected to the source of electrical energy and the secondary terminals those which receive the electrical energy.

19. *Synchronous Alternator for Alternating Currents, Single or Polyphase.*

Frequency, in periods per second.

Number of phases.

Output between terminals, in voltamperes (VA) or kilovoltamperes (kVA).

Pressure between terminals, in volts, corresponding to the rated output.

Power factor of the system to be supplied. If this is not specified it shall be taken as 0.8.

Current, in amperes.

Speed, in revolutions per minute.

Excitation pressure, in volts (if the alternator is not provided with a special exciter).

Maximum exciting current available, in amperes (if the alternator is not provided with a special exciter).

20. *Synchronous Motor for Alternating Currents, Single or Polyphase.*

Frequency, in periods per second.

Number of phases.

Mechanical output at the shaft, in watts (W) or in kilowatts (kW).

Current, approximate, in amperes.

Pressure, in volts, of supply available.

Speed, in revolutions per minute.

Unless otherwise specified, the motor must be capable of giving its rated mechanical output at unity power factor.

If the motor is required to act as a device for improving the

power factor, the value of the reactive power required shall be stated.

Excitation pressure, in volts (if the motor is not provided with a special exciter).

Method of starting to be employed and source of power available for this purpose.

Maximum exciting current available, if limited.

21. *Non-Synchronous Motor for alternating currents, Single or Polyphase*

Frequency, in periods per second.

Number of phases.

Mechanical power at the shaft, in watts (W) or in kilowatts (kW)

Pressure between terminals, in volts.

Current, approximate, in amperes.

Speed, in revolutions per minute, approximate, at the rated output.

Rotor, whether wound or squirrel cage.

Method of starting.

Unless otherwise specified it is assumed that the stator receives the supply current.

Starting torque in kilogrammes at one metre.

Ratio of the starting current to the current corresponding to the rated output.

Ratio of the starting torque to the torque corresponding to the rated output.

The last three items are to be stated for the motor with its starting accessories.

PART III. CONDITIONS TO BE FULFILLED BY ELECTRICAL MACHINERY.

VI. General Remarks.

22. *General.*—This section deals with the conditions to be fulfilled by a machine purporting to comply with the I. E. C. Rules.

VII. Limits of Temperature and Temperature Rise.

Temperature Limits.

23. *Table of Temperature Limits.*—The following table gives the limits for the observable temperatures and temperature rises of windings and of certain parts of machines.

The permissible temperature limits are indicated in column 1 of the table.

The permissible limits of temperature rise are given in column 2. The temperature rises measured on any machine which has worked for the specified time at the output corresponding with its I. E. C. rating shall not exceed in any of its parts the limiting values given in column 2 of the table. The highest permissible temperature given in column 1 and the temperature rises given in column 2 of the table should never be exceeded by a machine operating in service.

(For exception *see* Clause 27.)

TEMPERATURE LIMITS.

Item No.	Nature of the insulation of the winding or name of part.	*Column* 1. Highest permissible observable temperature.	*Column* 2. Highest permissible observable temperature rise for the purpose of fixing the international rating.
		Degrees C.	Degrees C.
1	Cotton, paper or silk, non-impregnated ..	80	40
2	" " " impregnated (*see* Clause 24)........................	95	55
3	Cotton, paper or silk, immersed in oil......	95	55
4	Enamelled wire (*see* Clause 25)	95	55
5	Mica, asbestos, glass, porcelain, micanite and similar compositions..............	115	75
6	Insulated windings permanently short circuited	100	60
7	Non-insulated windings permanently short circuited..........................	110	70
8	Oil (for temperature limits, *see* Appendix II.).	—	—
9	Commutators, slip rings (*see* Clause 27)....	90	50
10	Bearings	80	40
11	Iron core immersed in oil...............	95	55
12	Iron core in contact with windings.......	Same as the windings.	
13	Iron core not in contact with windings nor immersed in oil. The temperature and temperature rise shall not exceed that allowed for the windings themselves, and in no case shall the temperature and temperature rise exceed 110°C. and and 70°C. respectively.		
14	Single layer windings: An increase of 5°C. above the temperatures given for items 1, 2 and 4 shall be permitted in the case of coils, revolving or stationary, with single layer windings when not immersed in oil.		

24. *Impregnated Cotton, Paper or Silk.*—An insulation is considered to be "impregnated" when a suitable substance replaces the air between its fibres, even if this substance does not completely fill the spaces between the insulated conductors. The impregnating substance, in order to be considered suitable, must have good insulating properties; must entirely cover the fibres and render them adherent to each other and to the conductor; must not produce interstices within itself as a consequence of evaporation of the solvent or through any other cause; must not flow during the operation of the machine at full working load at the temperature limit specified; must not deteriorate under prolonged action of heat.

25. *Enamelled Wire.*—When employing the temperature limits in the table for enamelled wire the maker must satisfy himself that the enamel employed is of good quality.

26. *Compound Insulations made up of Different Materials.*—When the insulation consists of layers of several different materials, the lowest of the temperatures permitted for the different insulating materials employed (*see* Clause 23) is to be adopted as the limiting temperature. The insulating material, even when forming the support, shall always be assumed as forming part of the winding.

27. *Commutators and Slip Rings.*—The observable temperature and temperature rise of commutators and slip rings may exceed the values

given in item 9 of the table, provided that the three following conditions are fulfilled:—

(*a*) The temperatures of the insulating materials in the commutator and on the adjoining windings shall not exceed those allowed in the table for the insulating materials of those parts.

(*b*) The manufacturer shall give a special guarantee that the high temperature attained shall not impair the commutation.

(*c*) The temperature shall not be so high as to affect the quality of the soldered joints and the connections.

Reference Temperature of Cooling Medium.

28. *Reference Temperature of Cooling Medium.*—(*a*) *Temperate Climates.* In the absence of any indication to the contrary the maximum temperature of the air in which the machine is intended to operate in service shall be deemed to be 40°C.

(*b*) *Cold Climates.* In cold climates, when the actual temperature of the air in which the machine is intended to operate in service is not much different from 40°C. it is recommended that this conventional reference temperature of 40°C. should be adopted.

(*c*) *Tropical Climates.* The question of a reference temperature for cooling air for machines intended to operate in service in tropical climates will be dealt with by the I. E. C. at a later date.

(*d*) *Water Cooling* (*see* Appendix II.)

Permissible Limits for Temperature Rise.

29. *Permissible Limits for Temperature Rise.*—The limits permitted for temperature rise are deduced from the values allowed for the highest permissible observable temperature (*see* Clauses 23—27) by subtracting therefrom 40°C. (the value assumed as that of the maximum cooling air temperature of the place in which the machine may be required to work in service) (*see* Clause 28).

Temperature Measurements.

30. *Value of Temperature of Cooling Medium.*—A machine may be tested at any convenient cooling air temperature less than 40°C., but whatever be the value of this cooling air temperature the permissible rises of temperature shall not exceed those given in column 2 of the table (*see* Clause 23).

Corrections for variations in the cooling air temperature are not considered necessary within the limits of cooling air temperature obtaining in general practice.

In the case of cooling by means of forced ventilation the temperature of the air measured where it enters the machine shall be considered as the cooling air temperature.

For all machines cooled by other means, special rules will be necessary. (For water cooling, *see* Appendix II.)

31. *Measurement of Cooling Air Temperature during Tests.*—The cooling air temperature shall be measured by means of several thermometers placed at different points around and half-way up the machine at a distance of one to two metres, and protected from all heat radiation and draughts.

The value to be adopted for the temperature of the cooling air during a test shall be the mean of the readings of the thermometers (placed as mentioned above, taken at equal intervals of time during the last quarter of the duration of the test.

In order to avoid errors due to the time lag between the temperature of large machines and the variations in the cooling air, all reasonable precautions shall be taken to reduce these variations and the errors arising therefrom.

METHODS OF MEASUREMENT OF THE TEMPERATURES OF MACHINES.

32. *Measurement of the Temperatures of Machines.*—Two methods of determining the temperature of windings and other parts of machines are recognized:—

(*a*) Thermometer method.

(*b*) Resistance method.*

*NOTE.—With a view to brevity, the expression "method of variation of resistance of the winding" is replaced by the term "resistance method," or simply "by resistance."

33. *Thermometer Method.*—In this method the temperature is determined by thermometers applied to the accessible surfaces of the completed machine. The term "thermometer" also includes thermocouples and resistance-thermometers.

34. *Resistance Method.*—In this method the temperature rise of the windings is determined by the increase in the resistance of the windings themselves and checked by thermometers applied to the accessible surfaces of the windings to ascertain whether there is any higher local temperature. The highest of the temperatures thus found shall be taken as the observable temperature.

35. *Temperature of Windings.*—The temperature of windings as a rule shall be measured by the resistance method. The thermometer method alone is permitted in the following cases:—

(*a*) When it is not practicable to determine the temperature rise by the resistance method, as for example with low resistance commutating coils and compensating windings, and in general in the case of low resistance windings, especially when the resistance of joints and connections forms a considerable portion of the total resistance. In this case the temperature limits given in the table apply without correction.

(*b*) Single layer windings, revolving or stationary, when not immersed in oil. In this case an increase of 5°C. above the limits of temperature and of temperature rise given in the table is permitted.

(*c*) When, for reasons of manufacturing in quantity the thermometer method is used alone, although the resistance method would be possible. In this case the value of the highest permissible observable temperature and temperature rise given in the table shall be reduced by five degrees except in the case of stationary field coils, when the values given in the table shall be reduced by the difference between resistance and thermometer measurements as determined on similar machines, but in no case shall such reduction be less than 5°C.

36. *Corrections of Measurements taken after the machine has shut down.*—If the temperature is measured only after shut-down, the highest temperature attained while running shall be deduced by extrapolation on the time-temperature curve.

37. *Measuring Temperature of Direct-Current Generators and Motors.*—The temperature of field windings shall be measured in the manner described in Clauses 35 and 36.

The temperature of the armature shall be determined as a rule by thermometers placed on the windings at the hottest accessible parts, and when this method is employed the value of the highest permissible observable temperature and temperature rise shown in the table shall be reduced by 5°C.

38. *Measuring Temperature of Transformers.*—The temperature of transformer windings shall always be ascertained by resistance.

39. *Measuring Temperature of Synchronous Alternators and Motors.*—The temperature of the field windings shall always be ascertained by resistance. The temperature of stator windings shall be ascertained either by resistance or by thermometer in the manner described in the preceding clauses.

40. *Measuring Temperature of Non-Synchronous Motors without Commutators.*—The temperatures of the stator and rotor shall be ascertained in the same manner as those of the stator of a synchronous alternator (*see* Clause 39), except in the case of a permanently short-circuited winding, when the thermometer method shall be employed.

41. *Coefficients of Variation of Resistance of Copper with Temperature.*—In the case of resistance measurements the temperature coefficient of copper shall be taken from the values stated in the accompanying table, which have been deduced from the formula $1/(234.5 + t)$. Thus, at an initial temperature $t = 30$°C. the temperature coefficient or increase in resistance per degree Centigrade rise is $1/(264.5) = 0.00378$.

Temperature of the windings in degrees C., at which the initial resistance is measured.	Copper—increase in resistance per ohm per degree C.
0	0.00427
5	0.00418
10	0.00409
15	0.00401
20	0.00393
25	0.00385
30	0.00378
35	0.00371
40	0.00364

42. When the temperature of a winding is to be determined by resistance, the temperature of the winding before the test measured by thermometer shall not differ much from that of the cooling air.

43. *Duration of Temperature Test for Continuous Rating.*—For machines with I. E. C. continuous rating the temperature test shall be continued until it is evident that the maximum temperature rise attained

would not exceed the limits given in the table (*see* Clause 23), if the test were to be prolonged until the final steady temperature were attained. If possible, the temperature shall be measured both while running and after shut-down.

44. *Duration of Temperature Test for Short-time Rating.*—For machines with I. E. C. short-time rating the duration of the temperature test shall be that corresponding to the short-time test rating as indicated upon the rating plate.

At the commencement of the test the temperature of the machine must be practically that of the cooling air.

VII. Dielectric Tests.

(*See* Appendix III. for proposals.)

IX. Mechanical Tests.

(Not yet prepared.)

X. Commutation.

(Not yet prepared.)

PART IV. MARKINGS.

XI. Rating Plates.

45. *Rating Plate.*—Every machine shall bear the information necessary to define the limitations of the service for which it is intended.

For this purpose it shall have in all cases a rating plate and also such diagrams and terminal markings as may be necessary.

46. *Information on Rating Plate.*—The rating plate of a machine complying with the I. E. C. rules shall have a distinctive special sign and give the following information:—

(*a*) The name of the maker.
(*b*) The maker's machine number.
(*c*) The class of rating or the necessary information if the machine is intended to operate under more than one class of rating.
(*d*) The altitude at which the machine is intended to work if such altitude exceeds 1000 metres.
(*e*) The following technical information according to the character of the machine:—

In the absence of any indication in regard to the class of rating it is understood that the machine is intended for continuous service.

47. *Direct-current Generator.*

Generator—Direct-current.
Output, in watts (W) or in kilowatts (kW), with statement as to the class of rating.
Pressure between terminals, in volts.
Current, in amperes.
Speed, in revolutions per minute.

48. *Dierct-current Motor.*

Motor—Direct-current.
Output, in watts (W) or in kilowatts (kW), with statement as to the class of rating.
Pressure between terminals, in volts.
Current, approximate, in amperes.
Speed, in revolutions per minute.

49. *Transformer.*
Frequency, in periods per second.
Number of phases.
Apparent output at the secondary, in voltamperes (VA) or in kilovoltamperes (kVA), with statement as to the class of rating.
Primary pressure between terminals, in volts.
Secondary pressure, in volts, at no load and at rated load, with statement as to the power factor.
Short circuit pressure, in volts.
Secondary current, in amperes.
In addition, for three-phase transformers, a vector diagram indicating the method of connection of the windings in accordance with the figures. (*See* Appendix I.)

50. *Alternator.*
Frequency, in periods per second.
Number of phases.
Apparent output, in voltamperes (VA) or in kilovoltamperes (kVA), with statement as to the class of rating.
Pressure between terminals, in volts, corresponding to the rated output.
Current, in amperes.
Power factor corresponding to the rated output.
Speed, in revolutions per minute.
Excitation pressure, in volts.
Maximum exciting current, in amperes.

51. *Synchronous Motor.*
Frequency, in periods per second.
Number of phases.
Mechanical output, in watts, (W) or in kilowatts (kW), with statement as to the class of rating.
Pressure between terminals, in volts, corresponding to the rated output.
Current, approximate, in amperes.
If the motor is intended to work with a power factor different from unity, the necessary information to be given.
Speed, in revolutions per minute.
Excitation pressure, in volts.
Maximum exciting current, in amperes.

52. *Non-Synchronous Motor.*
Frequency, in periods per second.
Number of phases.
Mechanical output, in watts (W) or in kilowatts (kW), with statement as to the class of rating.
Pressure between terminals, in volts.
Current, approximate, in amperes.
Speed, in revolutions per minute, at rated output.
Maximum pressure between slip rings, in volts.

APPENDIX I.

At the meeting of the Advisory Committee on Rating held in September, 1913, the question of terminal marking and vector diagrams was referred to Messrs. Everest and la Cour. The following rules were forwarded to the Central Office, but as they have not been submitted to the National Committees, the Editing Committee decided to include them as an Appendix only. They will, therefore, be submitted to the next Plenary Meeting for ratification.

Terminal Markings for Transformers.

1. *Single-phase Transformers.*—The terminals of all single-phase transformers shall be marked with the letter T for the high pressure side and *t* for the low pressure side.

The neutral terminal, if provided, shall be marked by N or *n*.

The letters T and *t* should be accompanied by subscripts 0, 1, 2, etc., arranged in order of progression in the same direction as the electromotive force in each circuit at the same instant, as shown in the diagram.

If the transformer has two or more windings intended to be coupled in series or in parallel, the subscripts shall be single numbers for the first of such windings (1, 2, etc.), double numbers for the second windings (11, 22, etc.), and so on.

2. *Polyphase Transformers.*—The terminals of all polyphase transformers shall be marked as follows:—

(*a*) Phase Identification. The terminals of the high pressure and low pressure windings of any one phase shall be marked with the same letter, using capital letters on the high pressure terminals and small type letters on the low pressure terminals.

The letters, A. B. C. *a*. *b*. *c*. shall be used.

The neutral terminal, if provided, shall be marked N or *n*.

(*b*) Polarity Identification. The relative polarity of the corresponding high pressure and low pressure windings in each phase shall be indicated by the addition of subscripts (0) and (1) after the phase letters, so placed that at the instant when (in, for instance, phase A) the high pressure terminal marked A_1 is positive to terminal A_0, the low pressure terminal a_1 shall be simultaneously positive to that marked a_0.

Vector Diagrams for Polyphase Transformers.

3. *Polyphase Transformers connected together.*—When two or more polyphase transformers are to be grouped together with their windings connected to the same primary and secondary systems, it is essential that the transformers shall correspond, not only as regards the pressures for which they are intended, but also as regards the exact phase relation of the secondary winding to the primary winding.

4. *Scope of Vector Diagrams.*—All polyphase transformers shall bear a vector diagram which shows accurately the phase relation between primary and secondary terminals. To secure the correctness of such a diagram the following requirements shall be complied with:—

(*a*) The identification of each phase of the secondary winding with the corresponding phase of the primary winding shall be clearly indicated by the same terminal markings (*see* Paragraph 2 above).

(*b*) To avoid error arising from differences in methods of winding, the relative instantaneous polarity of primary and secondary windings in each phase shall be indicated at the terminals of the various phase windings (*see* Paragraph 3 above).

5. *Vector Diagrams.*—The vector diagram of connections shall show the phase letter and the polarity marking for each phase of the windings, and shall show correctly how the various phases are connected together. But to avoid the complexity of marking both phase letter and polarity mark at each end of every winding vector it shall be sufficient to show the phase letter once, together with an arrow head to indicate polarity, the arrow head in every case pointing away from that end of the phase which has the polarity mark (0) on its terminal.

6. The following are some typical vector diagrams which embody the principles laid down in these rules:

APPENDIX II.

This Appendix contains proposals prepared by the Advisory Committee on Rating for submission to the National Committees, but not yet presented to a Plenary Meeting for ratification.

1. *Temperature Limits for Oil.*

Temperature limit for oil measured by thermometer . .	90°C.
Temperature limit for the windings (measured by the increase of resistance) and other parts immersed in oil.	95°C.

Note.—The adoption of these temperatures implies the employment of a good oil of which the quality may be verified by ascertaining the flash point and measuring the deposit produced by heating.

The I. E. C. has not yet sufficient data to fix limiting values for the flash point or to prescribe the methods of measurement of the deposit.

2. *Reference Temperature of Cooling Water.*—For water-cooled apparatus, in the absence of any indication to the contrary, the maximum temperature of the cooling water in service shall be deemed to be 25°C. at the point of entry.

3. *Temperature Limits for Water-cooled Transformers.*—In the case of oil-immersed water-cooled transformers the limits of highest permissible observable temperature given in the table are to be reduced by 10°C.; therefore, the corresponding limits of temperature rise shown in the table may be increased 5°C.

APPENDIX III.

Dielectric Tests.

This Appendix contains proposals in regard to Dielectric Tests prepared by the Advisory Committee on Rating for submission to the National Committees, but not yet presented to the Plenary Meeting for ratification.

Dielectric Tests.—The high pressure test shall be applied between the winding and the frame with the core connected to the frame and to the winding not under test, and shall be applied only to a new and completed machine with all its parts in place under conditions equivalent to normal working conditions, and unless otherwise specified the test shall be carried out at the maker's works at the conclusion of the temperature test of the machine.

The test pressure shall be alternating, preferably of sine wave form.

The test shall be commenced at a pressure of less than one-third the test pressure and shall be increased to the full test pressure as rapidly as is consistent with its value being correctly indicated by the measuring instrument. The full test pressure shall then be maintained for one minute in accordance with the values as indicated in the following table:—

Item No.	Machine or Part.	Test Pressure (R. M. S.).
1	Rotating machines of size less than 1 kW................	500 V. + twice the rated pressure.
2	Rotating machines of size 1 kW to 3 kW................	1000 V. + twice the rated pressure.
3	Rotating machines of size above 3 kVA.............	1000 V. + twice the rated pressure with minimum, 2000 V.
4	Field windings for synchronous generators when the excitation pressure does not exceed 750 V.	10 times the excitation pressure. Minimum, 2000 V. Maximum, 3500 V.
5	Field windings for synchronous motors:—	
	(*a*) When intended to be started up with the field windings short circuited.	10 times the excitation pressure. Minimum, 2000 V. Maximum, 3500 V.
	(*b*) When intended to be started up with the field windings separated by a break-up switch.	5000 V.
	(*c*) When intended to be started up with the fields on open circuit and without a break-up switch.	5000 V. when the excitation pressure is less than 275 V. 8000 V. when the excitation pressure is equal to or exceeds 275 V.
6	Exciter......................	Not yet decided.
7	Transformers in general......	1000 V. + twice the rated pressure.

Item No.	Machine or Part.	Test Pressure (R. M. S.).
8	Transformers for primary pressures over 550 V., the secondaries of which are for direct connection to public or private distribution systems or public or private consumers (*i. e.*, secondary pressures less than 550 V.).	Primary windings: 1000 V. + twice the rated primary pressure with minimum, 10000 V. (adopted as a protection to human life). Secondary windings: 1000 V. + twice the rated secondary pressure.
9	Secondary (rotor) windings of induction motors not permanently short circuited.	For non-reversing motors: 1000 V. + twice the maximum pressure which could be induced between the slip rings. For reversing motors: 1000 V. + 4 times the pressure between the slip rings at standstill on open circuit with full primary pressure applied to tator windings.
10	Alternating current apparatus connected to a single-phase system of more than 300 V. pressure permanently earthed.	Not yet decided.
11	Assembled apparatus.........	When the test is made on an assembled group of several pieces of new apparatus each one of which has previously passed its high presure test, the test on such assembled group shall not exceed 85 per cent. of the lowest test pressure appropriate for any part of the group.

APPENDIX IV.

Definitions dealing with the subject of "Rating":—

Gt. Britain.—The rating of an electrical machine is the output assigned to it by the maker, together with the associated conditions, all of which are marked on the Rating Plate.

NOTE.—A machine may have a test rating or a service rating, or both, assigned to it, and marked on the rating plate.

United States of America.—The rating of a machine is the output marked on the Rating Plate and shall be based on, but shall not exceed

the maximum load which can be taken from the machine under prescribed conditions of test. This is also called the Rated Output.

(The term "maximum load" does not refer to loads applied solely for mechanical, commutation, or similar tests.)

France.—The rating of a machine is determined by the conditions of working such as speed, pressure, current, power factor, etc., as indicated on the Rating Plate.

Italy.—The output of a machine is the normal or average output, that is to say, the load at which the machine can work under normal conditions.

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